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Deciphering tectonic phases of the Amundsen Sea Embayment shelf, West Antarctica, from a magnetic anomaly grid

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ABSTRACT

The Amundsen Sea Embayment (ASE), with Pine Island Bay (PIB) in the eastern embayment, is a key location to understanding tectonic processes of the Pacific margin of West Antarctica. PIB has for a long time been suggested to contain the crustal boundary between the Thurston Island block and the Marie Byrd Land block. Plate tectonic reconstructions have shown that the initial rifting and breakup of New Zealand from West Antarctica occurred between Chatham Rise and the eastern Marie Byrd Land at the ASE. Recent concepts have discussed the possibility of PIB being the site of one of the eastern branches of the West Antarctic Rift System (WARS). About 30,000 km of aeromagnetic data – collected opportunistically by ship-based helicopter flights – and tracks of ship-borne magnetics were recorded over the ASE shelf during two RV *Polarstern* expeditions in 2006 and 2010. Grid processing, Euler deconvolution and 2D modelling were applied for the analysis of magnetic anomaly patterns, identification of structural lineaments and characterisation of magnetic source bodies. The grid clearly outlines the boundary zone between the inner shelf with outcropping basement rocks and the sedimentary basins of the middle to outer shelf. Distinct zones of anomaly patterns and lineaments can be associated with at least three tectonic phases from (1) magmatic emplacement zones of Cretaceous rifting and breakup (100–85 Ma), to (2) a southern distributed plate boundary zone of the Bellingshausen Plate (80–61 Ma) and (3) activities of the WARS indicated by NNE–SSW trending lineaments (55–30 Ma?). The analysis and interpretation are also used for constraining the directions of some of the flow paths of past grounded ice streams across the shelf.

1. Introduction

The Amundsen Sea Embayment contains one of the largest continental shelves of the Pacific margin of West Antarctica. Pine Island Bay, in the eastern part of the embayment, has for a long time been suggested to contain the crustal boundary between the Thurston Island block and the Marie Byrd Land block (e.g. Dalziel and Elliot, 1982; Grunow et al., 1991; Storey, 1991). Plate tectonic reconstructions suggest that this region was a key area for the initiation of continental breakup, that it was the location of a possible plate boundary, and that it may have been, or still is, an active branch of the West Antarctic Rift System (Dalziel, 2006; Eagles et al., 2004a; Gohl et al., 2007; Jordan et al., 2010; Larter et al., 2002; Wobbe et al., 2012). In spite of all this, little is known about the tectonic evolution and architecture of the embayment from direct study there.

Tectonically induced displacements of the crust are the underlying processes controlling the development of landscapes upon which climate processes play out. This context is of particular importance for reconstructing continental ice sheet evolution. In the Amundsen Sea Embayment, the Pine Island, Thwaites, Smith and Kohler glacier systems are thinning at rapid rates, and some of them have also started to flow at dramatically increased rates (e.g. Rignot et al., 2008; Pritchard et al., 2009). If these glaciers were to drain their catchment area, the volume of ice lost to the ocean could potentially lead to 1.5 m of sea-level rise (Vaughan et al., 2006). Modelling results (Pollard and DeConto, 2009) suggest that the ice sheet in the Amundsen Sea Embayment may have retreated with similar dynamics several times since the Pliocene. Identifying tectonic lineaments and understanding the tectonic architecture of the shelf of the Amundsen Sea Embayment may thus not only help explaining the geodynamic and kinematic processes of continental rifting in this West Antarctic realm, but also provide valuable constraints on flow paths and subglacial substrate of basement for palaeo-ice sheet modellers.

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An extensive ship-borne and helicopter-borne magnetic dataset was collected for the first time in the Amundsen Sea Embayment and Pine Island Bay by the Alfred Wegener Institute during RV *Polarstern* expeditions ANT-XXIII/4 in 2006 and ANT-XXVI/3 in 2010. The distribution and spacing of the survey tracks are suitable to allow spatial gridding and 3D field analysis for delineating crustal and basement features. In this paper, we describe the workflow from magnetic data acquisition to processing and modelling and put forward a model for the tectonic architecture of the offshore Amundsen Sea Embayment.

2. Geological and geophysical background

Fig. 2 summarizes the main stages in the tectonic development of the Pacific margin of West Antarctica. At least three distinct phases since Late Cretaceous have been discussed in recent literature.

The extension, and subsequent separation, of New Zealand and West Antarctica dominate the tectonic signature of the Amundsen Sea Embayment. This early divergence of the Pacific and Antarctic plates led first to rifting and crustal extension between Chatham Rise and the Amundsen Sea Embayment off easternmost Marie Byrd Land as early as 90 Ma (Eagles et al., 2004a; Larter et al., 2002; Wobbe et al., 2012). Rifting possibly continued within the Great South Basin between the Campbell Plateau and the South Island of New Zealand until its abandonment in favour of a new extensional locus to the south, forming the earliest oceanic crust between Campbell Plateau and Marie Byrd Land by 84–83 Ma.

From about 79 Ma, the Bellingshausen Plate moved independently of the Pacific and Antarctic Ridge on the southern flank of the Pacific–Antarctic Ridge until about 61 Ma, when a major plate reorganisation occurred in the South Pacific (e.g. Eagles et al., 2004a,b; Larter et al., 2002). This small plate's western boundary passed through the region of the Marie Byrd Seamounts, north of the Amundsen Sea Embayment. Its eastern transpressional boundary lies along the Bellingshausen Gravity Anomaly lineament in the western Bellingshausen Sea (Eagles et al., 2004a; Gohl et al., 1997). Although a discrete southern plate boundary has been depicted running from the seamounts onto the shelf and mainland, its true nature is poorly known (Eagles et al., 2004a,b) and it may be a more distributed feature.

The location of Pine Island Bay has led several researchers to suggest that it hosts a major crustal boundary between the Marie Byrd Land block to the west and the Thurston Island/Ellsworth Land blocks to the east. These blocks are suggested to have moved with respect to each other during the Late Cretaceous New Zealand–Antarctic separation and perhaps also in early Mesozoic or Palaeozoic times (e.g. Dalziel and Elliot, 1982; Grunow et al., 1991; Storey, 1991). However, direct evidence of the presence of such a boundary is still missing. Conceptual models also suggest that Pine Island Bay and the eastern Amundsen Sea Embayment hosted basins of the West Antarctic Rift System. Jordan et al. (2010) invert airborne gravity data to reveal an extremely thin crust and low lithospheric rigidity beneath the onshore Pine Island Rift. Müller et al. (2007) and Eagles et al. (2009) considered how, at times between chrons 21 and 8 (48–26 Ma), the West Antarctic Rift System east of the Ross Sea operated in either dextral strike-slip or extensional motion through the region to the south and east of the Amundsen Sea Embayment connecting eventually to a Pacific–Phoenix–East Antarctic triple junction via the Byrd Subglacial Basin and the Bentley Subglacial Trench. There are indications for an early West Antarctic Rift System extension in western Marie Byrd Land in the mid-Cretaceous (e.g. McFadden et al., 2010), but its eastern continuation is less well understood. It is possible that in the north–south striking zone of thinned crust in Pine Island Bay was an eastern arm of this early manifestation of the West Antarctic Rift System (Dalziel, 2006; Ferraccioli et al., 2007; Gohl et al., 2007; Jordan et al., 2010).

3. Magnetic surveys and data processing

The Amundsen Sea was the target area for geoscientific, oceanographic and biological studies during the RV *Polarstern* expeditions ANT-XXIII/4 in 2006 and ANT-XXVI/3 in 2010. Ship-borne magnetic data were continuously recorded with two 3-component fluxgate magnetometer sensors, which are permanently installed on the crow's nest. One of the two BO-105 helicopters on board was equipped with a caesium-vapour magnetometer sensor towed by a

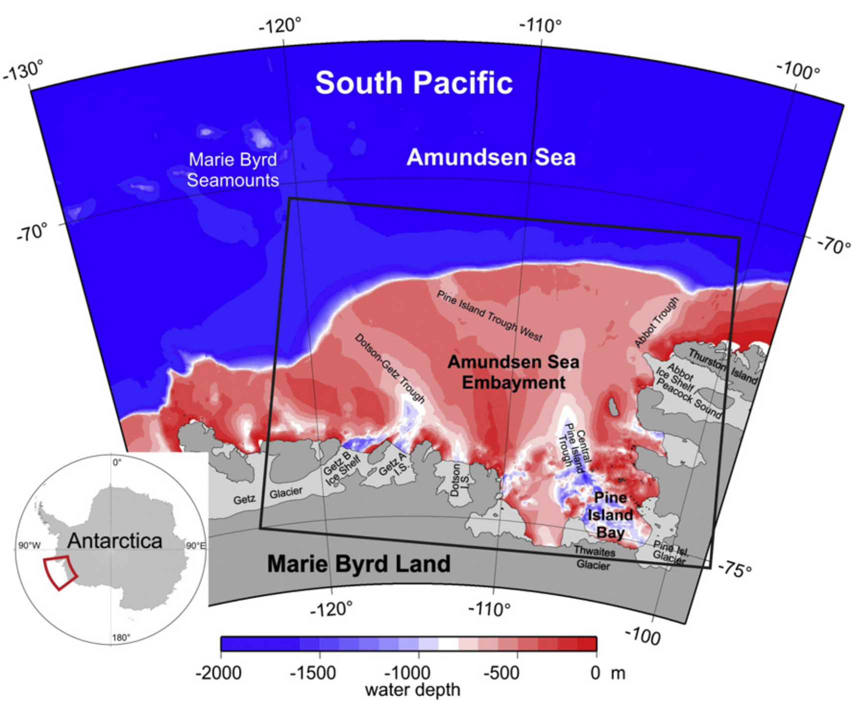

Fig. 1. Overview map of the Pacific margin of West Antarctica with the Amundsen Sea Embayment and Pine Island Bay. The bathymetry was compiled by Nitsche et al. (2007) and illustrates the glacially eroded deep troughs on the continental shelf. Middle grey areas are land regions with grounded ice, and light grey areas mark ice shelves. The black box marks the area of the magnetic survey shown and discussed in this paper.