Global and Planetary Change 123 (2014) 139–149

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Anomalous South Pacific lithosphere dynamics derived from new total sediment thickness estimates off the West Antarctic margin

Florian Wobbe [a,*], Ansa Lindeque [b], Karsten Gohl [a]

[a] Alfred Wegener Institute for Polar and Marine Research, Am Alten Hafen 26, 27568 Bremerhaven, Germany
[b] TGS Geophysical Company (UK) Limited, 1 The Crescent, Surbiton, Surrey, KT6 4BN, United Kingdom

ARTICLE INFO

Article history:
Received 18 January 2014
Received in revised form 22 September 2014
Accepted 25 September 2014
Available online 28 October 2014

Keywords:
Sediment isopach map
Sediment thickness grid
Sediment volume
Residual basement depth
Dynamic topography
Paleotopography

ABSTRACT

Paleotopographic models of the West Antarctic margin, which are essential for robust simulations of paleoclimate scenarios, lack information on sediment thickness and geodynamic conditions, resulting in large uncertainties. A new total sediment thickness grid spanning the Ross Sea–Amundsen Sea–Bellingshausen Sea basins is presented and is based on all the available seismic reflection, borehole, and gravity modeling data offshore West Antarctica. This grid was combined with NGDC's global 5 arc minute grid of ocean sediment thickness (Whittaker et al., 2013) and extends the NGDC grid further to the south. Sediment thickness along the West Antarctic margin tends to be 3–4 km larger than previously assumed. The sediment volume in the Bellingshausen, Amundsen, and Ross Sea basins amounts to 3.61, 3.58, and 2.78 million km^3, respectively. The residual basement topography of the South Pacific has been revised and the new data show an asymmetric trend over the Pacific–Antarctic Ridge. Values are anomalously high south of the spreading ridge and in the Ross Sea area, where the topography seems to be affected by persistent mantle processes. In contrast, the basement topography offshore Marie Byrd Land cannot be attributed to dynamic topography, but rather to crustal thickening due to intraplate volcanism. Present-day dynamic topography models disagree with the presented revised basement topography of the South Pacific, rendering paleotopographic reconstructions with such a limited dataset still fairly uncertain.

1. Introduction

The accurate reconstruction of paleotopography is the main prerequisite for robust simulations of paleoclimate scenarios. Current paleotopographic models contain large uncertainties due to absent or sparse sediment thickness data and constraints on geodynamic conditions. Since the Southern Ocean plays an important role in global climate processes, we assess the sedimentary and geodynamic conditions of the Southern Pacific to ascertain these essential factors for modern paleotopographic reconstructions.

We present an improved sediment thickness grid for the West Antarctic margin, which is now based on all the available seismic reflection, borehole, and gravity modeling data. This new grid spans the Antarctic Peninsula, Bellingshausen Sea, Amundsen Sea, and Ross Sea and links to Whittaker et al.'s (2013) data off Victoria Land. In the first part of this publication, we compare our results to previous work and discuss possible implications for paleotopography and paleoclimate reconstructions of Antarctica.

In the second part, we analyze and re-evaluate the Late Cretaceous to present lithosphere dynamics of the South Pacific after the final breakup of Gondwana. The rifted continental margins of New Zealand and West Antarctica experienced different tectonic histories: As New Zealand drifted away from Antarctica it was subjected to excess tectonic subsidence of 500–900 m, with a maximum during the interval 70–40 Myr (Spasojevic et al., 2010; Sutherland et al., 2010). The conjugate Marie Byrd Land margin, by contrast, was deformed by movement of the Bellingshausen plate relative to Antarctica (Wobbe et al., 2012), affected by intraplate volcanism (Kipf et al., 2013), and covered by large amounts of glacial sediments (e.g., Rebesco et al., 1997; Scheuer et al., 2006a). The West Antarctic margin and its adjacent seafloor is currently more than 1000 m shallower than the conjugate New Zealand margin. It has been suggested that mantle upwelling following the Gondwana subduction cessation could have caused this anomalously high topography (e.g., Storey et al., 1999; Sieminski et al., 2003; Winberry and Anandakrishnan, 2004; Finn et al., 2005; Spasojevic et al., 2010; Sutherland et al., 2010). In order to test this hypothesis with new data, we determined the sediment-corrected basement topography for the South Pacific and compared it to (i) an empirical sediment-corrected depth model from the North Pacific (Crosby et al., 2006), (ii) various dynamic topography models (e.g., Ricard et al., 1993; Steinberger, 2007; Conrad and Husson, 2009; Spasojevic and Gurnis, 2012; Flament et al., 2013), and (iii) a current mantle shear wave velocity model (Schaeffer and Lebedev, 2013). The differences

* Corresponding author.
E-mail address: fwobbe@awi.de (F. Wobbe).

http://dx.doi.org/10.1016/j.gloplacha.2014.09.006
0921-8181/

between the dynamic topography models are discussed and the implications for reconstructing the South Pacific paleobathymetry and paleotopography are highlighted.

2. Sediment thickness grids of the West Antarctic margin

We derived new 5 km and 5 arc minute resolution sediment thickness grids from seismic reflection and refraction data, from gravity models, and from data of selected drill sites on the West Antarctic margin of the Pacific (Ross Sea–Amundsen Sea–Bellingshausen Sea–Antarctic Peninsula).

2.1. Sediment thickness calculation

Total sediment thickness estimates of the continental margin and the deep ocean floor are largely based on multichannel seismic reflection surveys (Fig. 1). We used the two-way travel times (TWT) between the seafloor and the acoustic basement reflections along seismic reflection transects available from the Antarctic Seismic Data Library System (SDLS, Wardell et al., 2007, Table A.1 in the supplement) and along recently acquired and processed seismic profiles (e.g., ANT-18/5a, ANT-23/4, and ANT-26/3: Scheuer et al., 2006a,b; Lindeque and Gohl, 2010; Uenzelmann-Neben and Gohl, 2012; Wobbe et al., 2012; Gohl et al., 2013b; Kalberg and Gohl, 2014).

The TWT values, $2T$ in s, were converted to depth, Z in km, using Carlson et al.'s (1986) empirical relation $Z = 3.03\ln(1 - 0.52T)$. This method has been applied to seismic data acquired along the Antarctic Peninsula in past work (Rebesco et al., 1997; Scheuer et al., 2006a,b). Carlson et al.'s (1986) TWT–depth relationship is calibrated for sediments up to 1.4 km thick (~1.4 s TWT) only and the sediment thickness is considerably overestimated for TWTs larger than 2.8 s. This affects <5% of the data points, mainly located on the continental rise–slope transition. Due to the lack of area-wide seismic velocity models or downhole velocity measurements at drilling sites, we have to assume the acoustic velocity of sediments thicker than 2.8 s TWT.

P-wave velocities of 5–6 km thick sediments on the continental rise in polar regions typically range from 1800 to 4000 m s^{-1} (e.g., West Greenland, Chian et al., 1995; Suckro et al., 2012) or even 4200 m s^{-1} (e.g., East Greenland, Voss and Jokat, 2007). On the Amundsen Sea continental rise, sediment layer interval velocities from a P-wave refraction model (Lindeque and Gohl, 2010; Kalberg and Gohl, 2014) and from stacking velocities (Gohl et al., 2007; Uenzelmann-Neben and Gohl, 2012; Gohl et al., 2013b) range from 1600 to 4200 m s^{-1}. We determined the best fitting average acoustic velocity of sediments thicker than 2.8 s TWT to be 2818 m s^{-1} and converted all TWT values greater than 2.8 s to depth using this velocity.

The seismic data coverage of the Amundsen Sea Embayment shelf (Gohl et al., 2013b) is better than what the profiles used for this publication imply (Fig. 1). However, only few seismic lines reveal the top of basement, and those which do not were excluded. The limit of the sedimentary cover approaching the inner shelf is well documented (e.g., Gohl et al., 2013a,b, dotted line in Fig. 1).

2.2. Data merging and gridding

In order to extend data coverage of the mapped basement horizons from multichannel seismic data (Fig. 1) to the Ross Sea region, we incorporated total sediment thickness above the acoustic basement from Cooper et al. (1991). Wilson and Luyendyk (2009), whose data we included as well, estimated sediment thickness under the Ross Ice Shelf by extrapolating thickness trends in the Ross Sea from gravity anomalies. Four Deep Sea Drilling Project (DSDP) boreholes in the area of interest reach the basement. Their borehole depth measurements complement the sediment thickness data from the Ross Sea (sites 270 and 274, Hayes et al., 1975) and fill in the gaps of the most distal areas along the Antarctic Peninsula (sites 322 and 323, Hollister et al.,

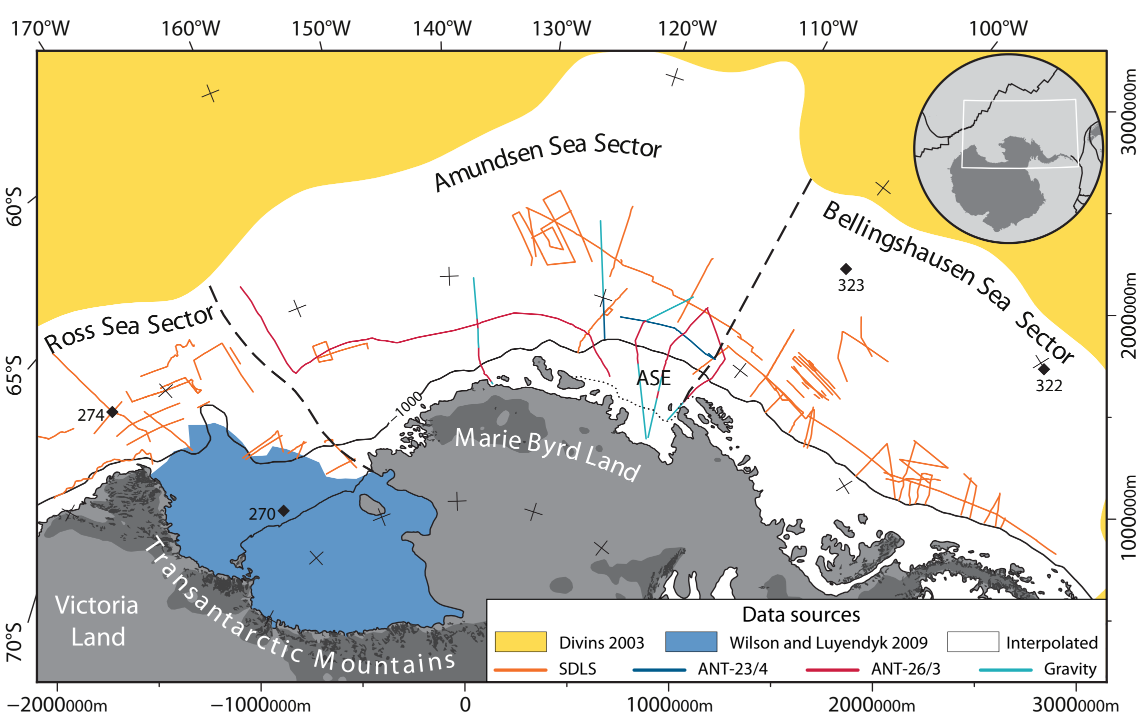

Fig. 1. Data sources used for compiling total sediment thickness and estimating sediment volumes. Areas based on gridded external data sources filled with solid colors (Divins, 2003; Wilson and Luyendyk, 2009). Data collected on transects are mostly multichannel seismic-reflection data available from the Antarctic Seismic Data Library System (SDLS, Wardell et al., 2007) and recent publications (ANT-23/4 and ANT-26/3: Scheuer et al., 2006a; Lindeque and Gohl, 2010; Uenzelmann-Neben and Gohl, 2012; Wobbe et al., 2012; Gohl et al., 2013b; Kalberg and Gohl, 2014). Some sediment thickness estimates in the Amundsen Sea sector are based on 2D gravity models (Wobbe et al., 2012). Dotted line outlines limit of sedimentary cover on inner Amundsen Sea Embayment (ASE) shelf (Gohl et al., 2013b). Polar stereographic projection with central meridian of 138°W and latitude of true scale at 71°S referenced to WGS84.