New aerogeophysical survey targets the extent of the West Antarctic Rift System over Ellsworth Land

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Summary The West Antarctic Ice Sheet is currently undergoing rapid change in particular over the Amundsen Sea Embayment (ASE). Previous aerogeophysical investigations over the Ross Sea Embayment reveal that the underlying geology may modulate ice sheet dynamics and hence stability. But what are the interplays between sub-ice geology and the apparently thinning and retreating glaciers of the ASE region? We will present new aerogeophysical data to provide a window on the "lithospheric cradle" for this part of the West Antarctic Ice Sheet, thereby contributing towards studying the largest glaciated continental rift system on Earth, the West Antarctic Rift System.

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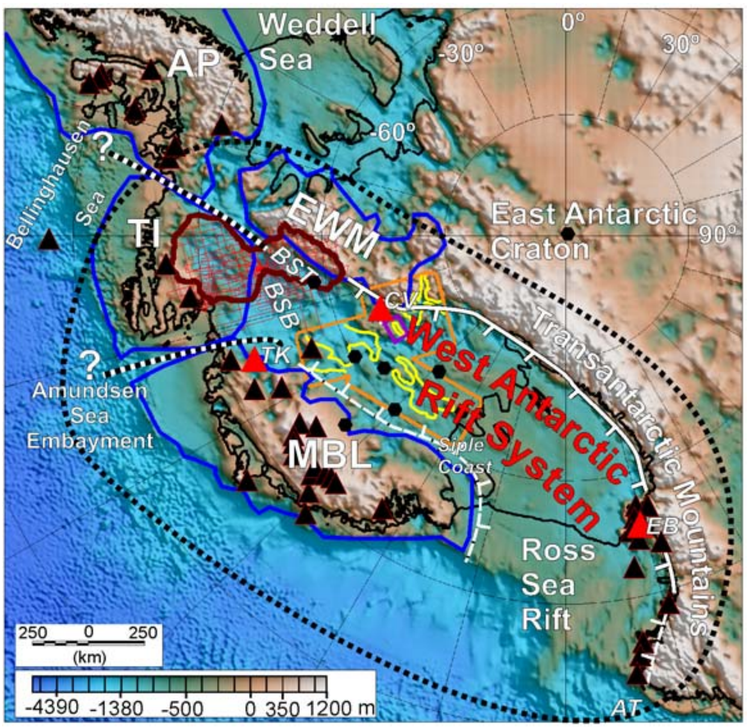

Figure 1. New BAS aerogeophysical survey (red lines). Note the West Antarctic Rift System and other tectonic blocks (TI: Thurston Island; MBL: Marie Byrd Land; EWM: Ellsworth-Whitmore Mountains; AP: Antarctic Peninsula). The extent of the WARS beneath the Byrd (BSB) and Bentley subglacial basins (BST) and its possible connection to the Amundsen \Bellinghausen seas (black and white lines) is poorly constrained (Dalziel, 2006). PIG catchment: brown. Inferred mantle plume head (dotted) (Behrendt, 1999). Rift basins (yellow) traced from previous aerogeophysics (orange). Cenozoic volcanoes: black triangles; red active (EB-Mount Erebus; TK- Mt Takahe; CV- Casertz volcano). Magnetotelluric experiment (purple box) from Wannamacker et al., (1996). Seismic stations (black circles) from Winberry and Anandakrishnan, (2004). AT: Adare Trough (Cande et al., 2000).

Introduction

There are growing concerns over how the West Antarctic Ice Sheet (WAIS) will respond to global warming and the implications that its potential collapse would have for global sea-level rise. An area of particular international concern is the Amundsen Sea Embayment (Fig. 1), where glaciers such as Pine Glacier (PIG) and Thwaites Glacier (THW) appear to be melting, thinning, accelerating and retreating rapidly (Rignot et al., 2004, Thomas et al., 2004). This part of the WAIS has been referred to as the "weak underbelly" of the WAIS, i.e. a sector of the ice sheet, which may be prone to catastrophic collapse (Hughes, 1981).

Aerogeophysical surveys performed over the Ross Sea Embayment (RSE) have imaged subglacial geological boundary conditions and have highlighted their importance for the dynamics and hence stability of the overlying WAIS. Tectonic and magmatic structures associated with the West Antarctic Rift System (WARS), may modulate the dynamics of the WAIS (Bell et al., 1998; Behrendt, 1999; Studinger et al., 2001; Dalziel and Lawver, 2001). High-heat flow could potentially be associated with Cenozoic to Recent volcanism within parts of the rift system (Blankenship et al., 1993; Behrendt et al., 1998). High geothermal flux could increase basal melting thereby enhancing the availability of water, which is critical to the initiation and maintenance of fast-flowing ice streams (Hulbe and MacAyeal, 1999). Suglacial sediments infilling narrow rifts (Studinger et al., 2001) or broader "extended terranes" (Bell et al., 2006) may provide a geological template for enhanced

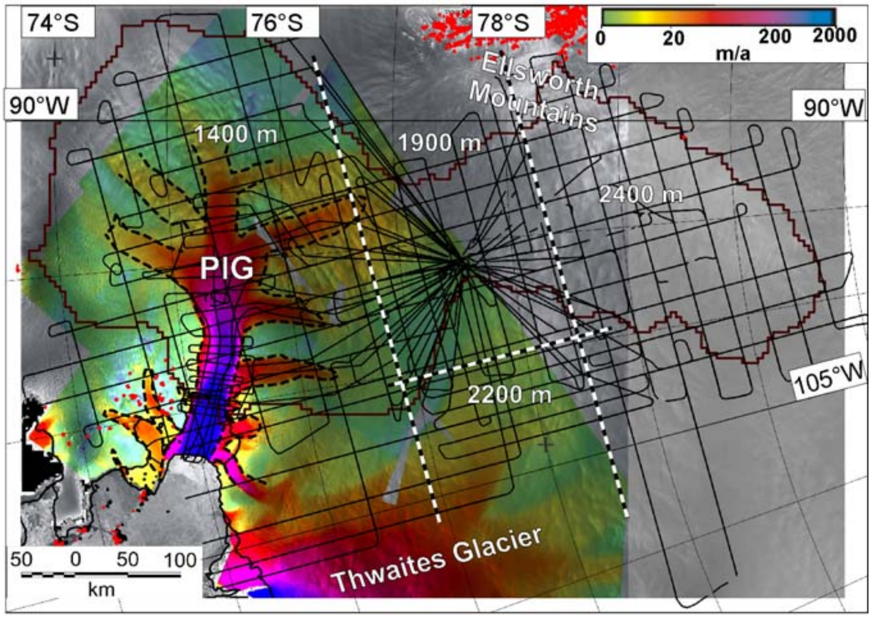

Figure 2. Flight lines over the PIG catchment and ice velocities (Rignot et al., 2004). Red dots mark rock outcrops.

ice flow over the RSE region. However, does the WARS extend beneath the Amundsen Sea Embayment (ASE) region (Dalziel, 2006), and if so, what role do rift structures and associated magmatic features play for this dynamic sector of the WAIS? A collaborative aerogeophysical campaign was flown by the University of Texas (UT) and the British Antarctic Survey (BAS) over the catchments of THW and PIG (Holt et al., 2006; Vaughan et al., 2006), which will significantly enhance our knowledge of the WARS, and its boundaries to the adjacent crustal blocks of West Antarctica (Fig. 1). Here we focus mainly on the BAS survey over PIG. The aerogravity investigation over THW and the adjacent RSE region is described by Diehl et al., (this volume).

New aerogeophysical survey

During the austral summer of 2004/2005, the first systematic aerogeophysical survey of the ASE region was undertaken, including radio-echo sounding, aeromagnetic and airborne gravity data collection. A BAS Twin Otter aircraft was used to explore mainly the PIG catchment, and collected 32,000 line km of new data over 32 flights (Fig. 2). Out of these, 5 flights were flown over the THW catchment to provide more detailed coverage of the eastern margin of THW glacier (Holt et al., 2006) and the Byrd Subglacial Basin. Aerogravity data need to be acquired at a constant elevation, so 27 flights were flown on an approximately 30 km grid mesh along three blocks at a nominal constant altitude of 1400 m, 1900 m and 2400 m. Terrain clearance varied from a minimum of 50 m to a maximum of 600 m to ensure that we would recover reliable bedrock reflections from the airborne radar. The transfer sections were flown in draped mode at 150 m nominal terrain clearance, which provided enhanced bedrock and ice layering returns. The relatively wide line spacing reflected a compromise in order to survey a large enough area to be significant for ice sheet models addressing the stability of this dynamic part of the WAIS (Vaughan et al., 2006). Although this is a coarse grid in particular for aeromagnetics, a similar BAS survey over Coats Land (East Antarctica) suggests that regional subglacial geology can still be delineated by utilising aeromagnetic profile data analysis (Bamber et al., 2006). Five flights were flown in draped mode with a line spacing of 3-9 km over the PIG trunk and its tributaries, thereby providing a more detailed window on subglacial topography and geology for this key feature.

Main Survey Aims

Image subglacial topography

Numerical models to make predictions on the stability of the WAIS require knowledge of ice thickness and bedrock topography. The first aim of our surveys was therefore to provide improved grids for the ASE region compared to BEDMAP. Knowledge of ice thickness and bedrock configurations is also essential to perform the complete Bouguer anomaly correction for airborne gravity data reduction (Jones et al., 2002) and to drape aeromagnetic data (Pilkington and Thurston, 2001). Sub-ice morphology and terrain roughness (or smoothness) can also provide important insights into the tectonic and geological setting (e.g. Wilson and Luyendyk, 2006).

Figure 3 shows a new 3D perspective of the subglacial topography for the ASE region (Vaughan et al., 2006; Holt et al., 2006). The Marie Byrd Land block has high volcanic topography, which is clearly distinct from the low-lying regions, interpreted as delineating the WARS. A remarkable boundary is revealed between the Bentley Subglacial Trench and the Ellsworth-Whitmore Mountains block, likely representing the rift flank. The Byrd Subglacial Basin appears to have a relatively smooth bed, which may reflect the existence of a sedimentary infill (Fig. 2 in Diehl et al., this volume). The trunk of PIG lies in a narrow, 250-km long trench flanked to the north by a prominent highland, the Hudson Mountains, and to the south by a sinuous-shaped bedrock high (H in figure 3). In contrast, THW flows in a much broader basin suggesting a less prominent degree of structural control over the main trunk (Holt et al., 2006).

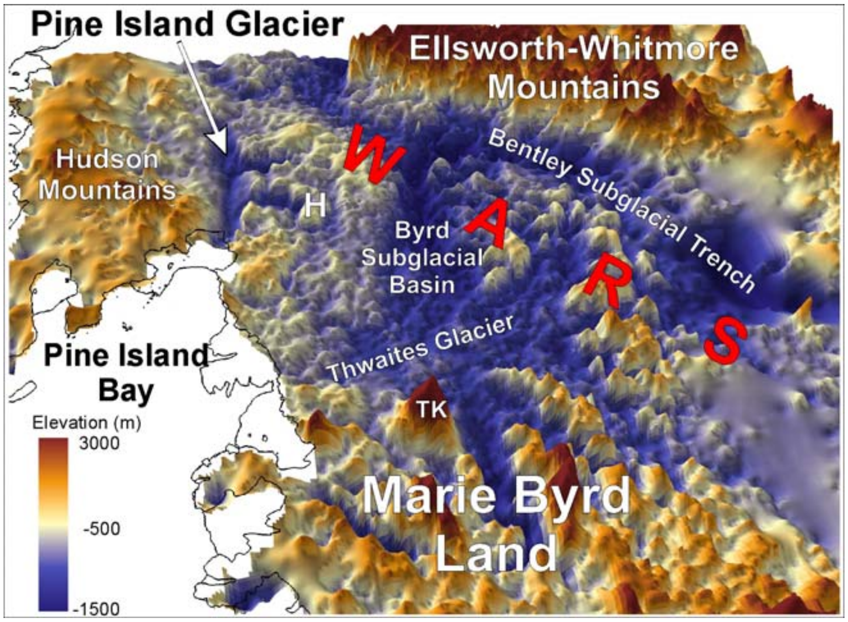

Figure 3. 3D perspective of subglacial topography over Ellsworth Land.

Assess the extent and distribution of Cenozoic magmatism

Previous aeromagnetic surveys over central West Antarctica have revealed high-amplitude, short-wavelength magnetic anomalies, interpreted as subglacial intrusions associated with the Oligocene to Recent alkaline volcanism of the WARS (Behrendt et al., 2004; Le Masurier, 2006). High-gradients of these anomalies suggest shallow sources, but the lack of prominent topographic expression for the majority of these anomalies indicates that most volcanic edifices were glacially removed, similar to the case in Iceland (Behrendt et al., 2004). Over 44% of the previously surveyed regions contain these anomalies suggesting a highly magmatic rift, with estimated volumes of 10^6 km^3 (Behrendt et al., 2004). Active volcanoes of the Marie Byrd Land province extend as far east as Mount Takahe (TK in Fig. 3) and Miocene-Pliocene basalts and tuffs are exposed in the Hudson Mountains (LeMasurier and Thomson, 1990). We will utilise the new aeromagnetic data to trace Cenozoic magmatic patterns beneath PIG, Byrd Subglacial Basin and Bentley Sublacial Trench (if they exist) and to assess if tectono-magmatic segmentation of the rift occurs.

Image the extent of subglacial sediments

Aeromagnetic data provide a tool to estimate depth to basement, which is often taken as a proxy for the thickness of sedimentary infill within basins. Inversion of aeromagnetic data has imaged sedimentary infill beneath the Siple Coast basins, Ross Sea Rift and in Coats Land (Bell et al., 2006; Bamber et al., 2006). Isostatic gravity anomalies, terrain de-correlated gravity anomalies, and 3D gravity inversion can also significantly enhance the location and characterisation of rift basins with sedimentary infill (Jones et al., 2002; Ferraccioli et al., 2005; Diehl et al., this volume). We will therefore use a combination of aeromagnetics and aerogravity to image subglacial sediments under the PIG catchment and to assess their possible influence on ice flow dynamics.

Estimate crustal thickness and lithosphere rigidity

Wide-angle seismic experiments across the Ross Sea Rift suggest significant crustal stretching ($1.6<ß<4.0$) within that segment of the WARS (Trey et al., 1999). The western part of the Ross Sea Rift was affected by Cenozoic rifting, perhaps associated with opening of the Adare Trough (Cande et al., 2000). Power spectral analysis of aerogravity data and seismic refraction measurements over the Bentley Subglacial Trench suggest $ß=1.3$, which may imply a weaker influence of Cenozoic rifting here (Studinger et al., 2002; Clarke et al., 1998). However, 21 km thick crust has been estimated beneath one station further east over the Bentley Subglacial Trench from receiver-function analysis suggesting extreme local(?) extension in Ellsworth Land (Winberry and Anandakrishnan, 2004). We will utilise decorrelation and gravity inversion techniques (Jones et al., 2002; Ferraccioli et al., 2005) to re-assess crustal thickness under the PIG catchment, thereby providing a new window on the extent of rifting over the region. Gravity and topography data will also be used to estimate the rigidity of the lithosphere, thereby providing important constraints on rift evolution (e.g. Karner et al., 2005) and isostatic rebound in response to deglaciation (e.g. Wilson and Luyendyk, 2006).

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