SCAR Fellowship 2007-08 – Final Report

Title: Structural controls and timing of upper crustal deformation within the Lambert Basin: Contribution to geodynamic, ice-sheet and mass balance models of the Mesozoic-Tertiary evolution of East Antarctica

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Introduction

The Lambert Graben is considered to represent a failed rift system that formed in central East Gondwana during the Carboniferous to Cretaceous (350–100 Ma). Geophysical studies show that the Graben extends approximately 700 kilometres from the interior of Antarctica to the coastline at Prydz Bay in Mac.Robertson Land. Significantly, approximately 1/5 of the East Antarctic ice sheet is drained into the Southern Ocean along the Lambert Graben; making this geological structure the largest conduit of ice flow in Antarctica. The timing and structural controls responsible for the development of the Graben are however topics of considerable debate, which in turn create significant uncertainties as to the processes responsible for topography development in this region of Antarctica. To address these uncertainties, the proposed research had two aims:

1) To develop a kinematic model of graben evolution through the inversion of palaeostress data collected from brittle deformation features that formed during the development of the Lambert Graben;
2) To determine the timing of deformation events through isotopic dating of fault gouges.

The desired result was to develop a time integrated kinematic model for upper crustal deformation related to the development of the Lambert Graben. In doing so, inferences on the development of topography prior to the glaciation of Antarctica could be made.

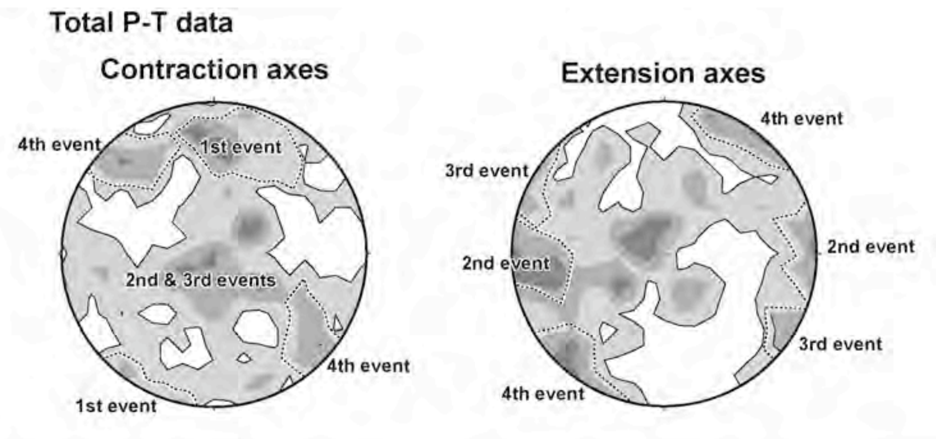
Methodology

The strength of the proposed research was the processing and interpretation of a large database collected by Phillips and Läufer on the Prince Charles Mountains Expedition of Germany and Australia in 2002-03. Approximately 760 faults were measured during fieldwork in the Lambert Graben region, which were used to reconstruct the kinematic evolution (or stress fields) responsible for the development of the Graben. Firstly, overprinting relationships between faults were used to determine a relative framework of deformation events (Läufer & Phillips, 2008; Terra Antartica 14, 61-68). Secondly, the inversion of kinematic data allowed the calculation of stress fields responsible for movement along a specific fault plane (Phillips & Läufer, 2009, see publication list). Combined, these techniques indicate that the evolution of the Lambert Graben was: **(i)** polyphase; **(ii)** associated with two dominant continental dispersion events during the Carboniferous–Permian and Cretaceous, and; **(iii)** was probably a necessary precursor for the present day distribution of topography in the southern Prince Charles Mountains.

In addition, K-Ar isotopes in rock samples were measured to further constrain the timing of deformation events through the identification of periods of elevated temperatures associated with faulting (i.e., shearing, fluid injection). K-Ar isotopes in fine-grained mica can be extremely sensitive to slight thermal changes, and therefore, these mineral phases were targeted for dating. However, owing to the difficulties surrounding the separation of fine-grained mica (the freeze-dry fracture method was employed), as well as restrictions on instrument time, dating results are yet to be finalized. Samples are awaiting final analysis at The John de Laeter Centre at The University of Western Australia. Deformation ages could however be estimated by preexisting geochronological constraints on the timing of basement denudation and uplift (Lisker et al., 2003; Tectonics 22, doi:10.1029/2002TC001477).

Results

Overprinting relationships, stress inversions of kinematic data and preexisting geochronological data indicate that at least four main deformation events were responsible for the development of the Lambert Graben (Fig. 1). Ductile–brittle deformation structures including shear zones and brittle faults are related to the earliest event, which occurred during northeast-southwest contraction and sub-vertical extension (Fig. 1). Owing to preexisting $^{40}Ar/^{39}Ar$ isotopic data from mica extracted from shear zones (Phillips et al., 2007; J. Geol. Soc. London 164, 771-784) that formed in a comparable stress field, it could be concluded that these structures formed in the early Palaeozoic (~ 500 Ma). Following this, a dominant period of east-west extension and sub-vertical to north-south contraction was responsible for the incipient development of the Graben by pure extension. The timing of this event can be constrained to the Carboniferous to Permian by apatite fission track data (Lisker et al., 2003). Overprinting structures that formed under northwest-southeast extension and sub-vertical to northeast-southwest contraction were the next to form. These structures can be linked to a second period of basement denudation, this time during the Cretaceous; also constrained by apatite fission track data (Lisker et al., 2003). Finally, late-stage brittle structures that formed during northwest-southeast contraction and sub-vertical to northeast-southwest extension are the youngest brittle deformation features preserved in the southern Prince Charles Mountains. The time that these structures formed is difficult to establish from the preexisting geochronology.



Event	1st	2nd	3rd	4th
Stress field	NE-SW contraction	Subvertical to NS contraction	Subvertical to NE-SW contraction	NW-SE contraction
	Subvertical extension	EW extension	NW-SE extension	Subvertical to NE-SW extension
Timing	~ 500 Ma	350-300 Ma	~ 120 Ma	< 45 Ma (?)

Fig. 1. Summary and interpretation of kinematic data collected from the brittle deformation structures in the southern Prince Charles Mountains. Top: stereographic projection of contractional and extensional stress axes from 767 faults. Grouping of these data allow inferences to be made on the regional stress fields responsible for deformation. Bottom: Table summarising palaeostress fields and approximate ages responsible for each deformation event.

Relevance to projects aims

The underlying aim of the proposed research was to reconstruct basement topography in the Lambert Graben region prior to the Eocence glaciation of Antarctica (i.e., contribute towards **Eocence-Oligocene ACE sub-committee).** The present study shows that the dominant brittle deformation features that define the Lambert Graben probably formed prior to the Cretaceous (> 100 Ma). Even though it is indicated that the main crustal deformation events occurred prior to the Eocene, this study has shown that lithospheric isostasy in the region must have been dynamic since the Cretaceous period. Firstly, this study has revealed that bedrock lineaments in the southern Prince Charles Mountains and northern Gamburtsev Mountains parallel the orientation of the main fault zones that formed during graben evolution (Fig. 2). This provides an important link between brittle deformation structures preserved in the exposed bedrock of the southern Prince Charles Mountains, and major ice-covered bedrock lineaments that define the Lambert Graben and neighboring topography (i.e. Gamburtsev Mountains). Secondly, as it has been previously suggestion that the exposed flat-topped nunataks and escarpments in the southern Prince Charles Mountains preserve a pre-Oligocene fluvial erosion surface (Bardin, 1977; Polar Geography 1, 251-269), it is reasonable to suggest that the current topography is related to recent processes that have occurred since Eocene times. Furthermore, there is a clear lack of evidence for tectonic activity in this region of Antarctica over the last 50 million years, so it is highly unlikely that the present day topography was related to tectonic process. Based on these lines of reasoning, it has been concluded in a recent paper by Phillips & Läufer (2009) that the present day topography is probably related to dynamic uplift related to glaciation, intensive bedrock incision and dynamic isostasy along the Lambert Graben. On the basis of this interpretation and the clear spatial link between bedrock lineaments and ancient fault zones, it is suggested that ancient faults were probably the sites of reactivation during dynamic isostasy caused by plate unloading and flexure. This, in turn, accommodated maximum uplift in the southern Prince Charles-Gamburtsev Mountains region (*see* Phillips & Läufer 2009 for complete discussion).

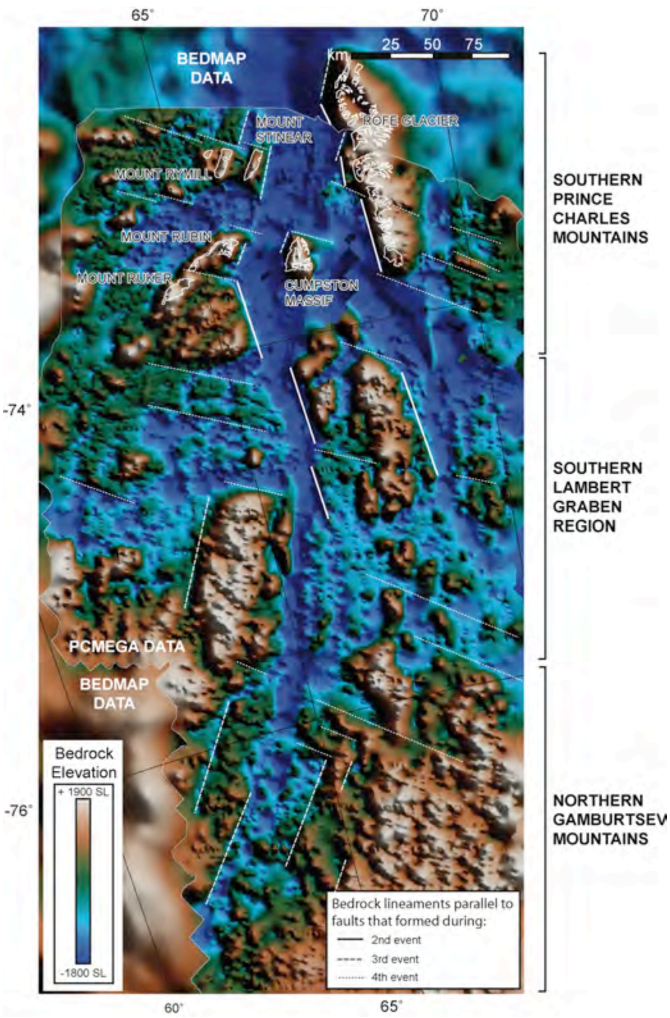


Fig 2. Bedrock elevation model of the southern Prince Charles Mountains to Gamburtsev Mountains. Interestingly, bedrock lineaments that define topography approximate the orientation of the main fault zones identified in the southern Prince Charles Mountains.

Future Work

Future work will be centered on numerical modeling to determine the influence of glacial incision, plate unloading and upward flexure on the development of topography in the southern Prince Charles-

Gamburtsev Mountains region. Studies from the Transantarctic Mountains clearly show that glacial incision can result in significant uplift (Stern et al., 2005; Geology 33, 221-224) in glaciated regions. A similar approach will be employed to model geomorphologically controlled uplift in the southern Prince Charles–Gamburtsev Mountains.

Publications

Phillips, G., & Läufer, A.L., 2009. Brittle deformation relating to the Carboniferous–Cretaceous evolution of the Lambert Graben, East Antarctica: a precursor for Cenozioc relief development in an intraplate and glaciated region. Tectonophysics. *inpress.*

Budget Justification

Total amount: ~ $ 12 000 AUD

Return Flights Sydney to Frankfurt - $ 2500 AUD

Travel and accommodation within Europe including visits to Viena and Bremen for collaboration - $ 1000 AUD

Accommodation and subsistence while visiting Hannover (2.5 months) - $ 2000

External hardrive for data storage and transportation - $ 500

Publication costs: $ 600

K-Ar and Ar-Ar isotopic analyses at The John de Laeter Centre, Western Australia - $ 5400