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Jurassic failed rift system below the Filchner-Ronne-Shelf, Antarctica: New evidence from geophysical data

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ABSTRACT

During the austral summer of 1994/95, reasonable ice conditions in the Weddell Sea allowed the acquisition of new high quality seismic refraction data parallel to the Filchner-Ronne Ice Shelf (FRS), Antarctica. Although pack ice conditions resulted in some data gaps, the final velocity-depth/2D-density models cover the entire FRS in E-W direction using all available deep seismic data/picks from this remote area. The velocity-depth model shows a sedimentary basin with a thickness up to 12 km and a large velocity inversion in the lowermost sedimentary unit. The crustal thickness reaches a maximum of 40 km along the basin's margins in the Antarctic Peninsula and East Antarctica. In the central shelf area, numerous interfering seismic phases occur from the crust-mantle boundary at decreasing distances indicating a thinning of the crust. Here, the modelled velocities and densities reveal a thickness of 20 km for the igneous crust. This corridor of overthickened oceanic or close to oceanic crust is 160 km wide. The corridor is characterized by weak, but in general continuous magnetic anomalies, which we interpret as isochrons developed during the rifting or the initial formation of oceanic crust. If the crustal composition represents an old stripe of oceanic crust, a minimum estimate for the early formation of the oceanic crust is 145/148 Ma (Late Jurassic). However, based on the velocity of rift propagation during the initial opening of the adjacent Weddell Sea the oceanic crust is likely to have formed around 160 Ma. The onset of rifting and development of a thick igneous crust can be related to stresses developed between the interior and the southwestern paleo-Pacific subduction margin of the fragmenting Gondwana supercontinent in combination with additional melt supply from a deeper mantle source that arrived and spread in the period 183–155 Ma.

1. Introduction

Based on contrasts in its geological history, the Antarctic continent can be subdivided into two parts, East and West Antarctica. East Antarctica (EANT) hosts one of the world's largest collections of cratonic fragments, along with those of southern Africa and Australia. Geological/geophysical investigations along the rims of EANT reveal the traces of Grenvillian and pan-African orogenies that led to the cratons' amalgamation. However, because of its 4 km thick ice sheet, few details are known about the geology of EANT's interior. West Antarctica (WANT) has also a geologically old core comprised of a number of crustal blocks whose origin and relative motions through geological time have been the subject of decades of controversy (Grunow, 1993; Curtis and Storey, 1996; Hübscher et al., 1998). The controversy arises mainly from the paucity of outcrop and other data, and partly from WANT's involvement in Cretaceous/Cenozoic subduction and rifting events, which appear to be related to ongoing volcanism below the Ross Ice shelf (RIS) and West Antarctic and Antarctic Peninsula ice sheets (Behrendt et al., 1996).

The present-day margins of EANT and the western part of WANT are all rifted margins that formed during the break-up of Gondwana in Late Jurassic to Late Cretaceous times. Along the Antarctic Peninsula, in contrast, a formerly convergent plate margin saw subduction of the former Phoenix plate that ceased during a succession of ridge-trench collisions along the Pacific WANT margin in Cenozoic times (Larter and Barker, 1991). Today, active relics of this subduction might only be found at the northern tip of the Antarctic Peninsula (AP), where subducted parts of the Phoenix plate continue to sink into the mantle after its surface parts were incorporated into the Antarctic plate at ~3 Ma (Barker, 1982; Henriet et al., 1992).

WANT is separated from EANT across two vast continental shelf areas, the Filchner-Ronne-Shelf (FRS) in the Atlantic sector and the Ross Shelf (RS) in the Pacific sector. Each of the shelves is up to 800 km wide and hosts huge sediment basins with sedimentary thicknesses of up to 13 km. The crustal fabric of the Filchner-Ronne Shelf constitutes an important constraint on kinematic models of the movements

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of the Antarctic Peninsula relative to EANT. The deep seismic sounding data along the FRS ice shelf edge (Figs. 1, 2) presented in our study will partly reveal this crustal fabric. The data give a detailed insight into the sedimentary structure and deeper crustal structure of the northern FRS. The Filchner-Ronne-Shelf-Crustal-Transect (Fig. 2, FRSCT) presented here, is a combination of our results with those of previous studies (Hübscher et al., 1998; Leitchenkov and Kudryavtzev, 2000; Table 1) to construct the most complete crustal model for the area.

2. Experimental setup and data processing

During the austral summer of 1994/95, reasonable ice conditions in the southwestern Weddell Sea (Fig. 2a) allowed the acquisition of seismic reflection and refraction data parallel to the Filchner-Ronne Ice Shelf (Jokat et al., 1997). The experiment was performed opportunistically after catabatic winds opened a narrow polynya along the ice edge over a period of a few hours, enabling FS *Polarstern* to steam towards the AP. Work was carried out quickly in the knowledge that a

a

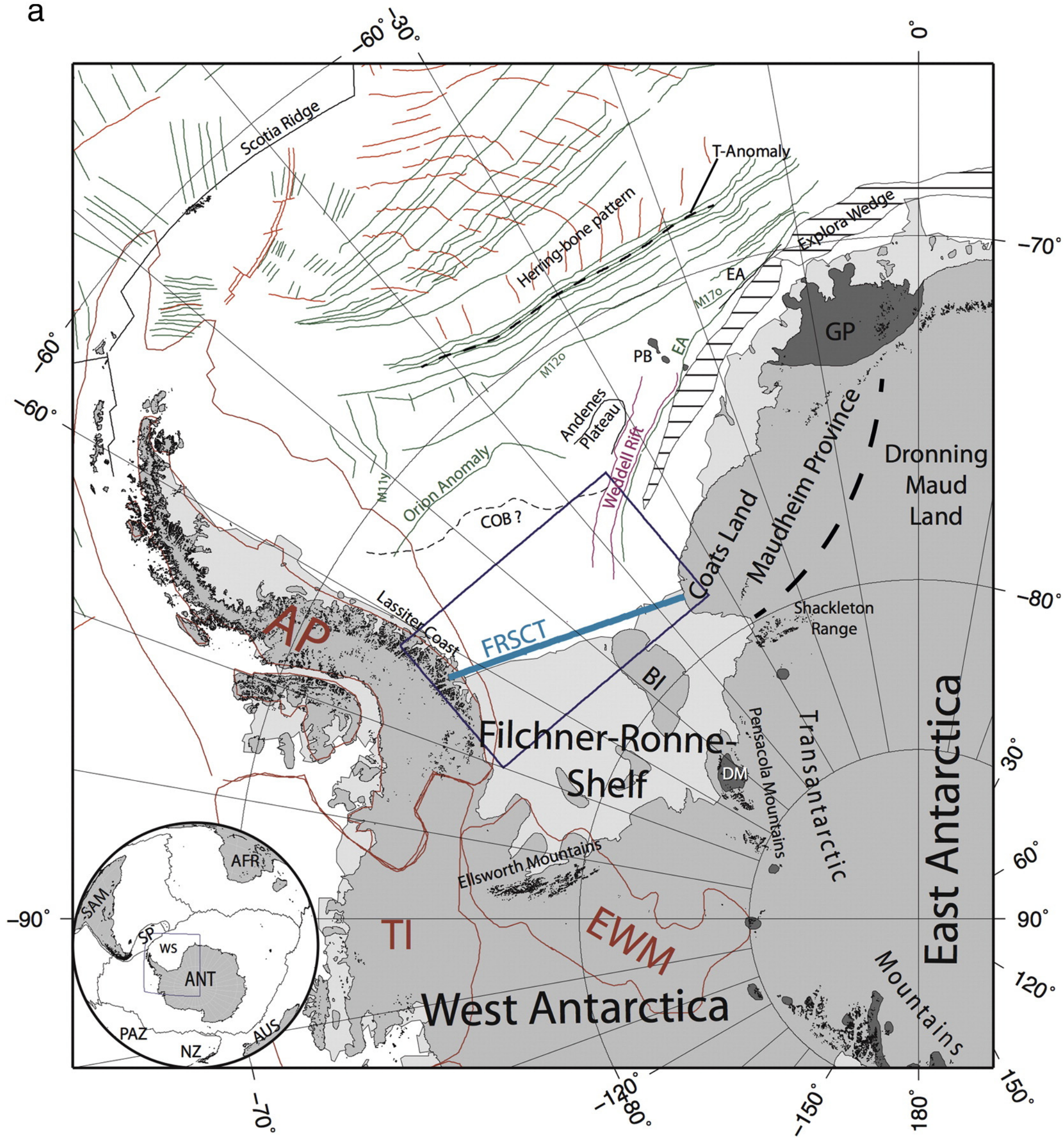

Fig. 1. a: The Weddell Sea and its tectonic features: dark red contours: boundaries of crustal blocks in West Antarctica (Coffin et al., 1998). Green: magnetic spreading anomalies, after Ferris et al. (2000); König and Jokat (2006). The sea floor of the northern Weddell Sea shows East-West striking as well as North-South striking anomalies. The characteristic herringbone pattern (transform faults in red) arises due to a sharp decrease of the spreading velocity to ultraslow rates (Livermore and Hunter, 1996; Rogenhagen and Jokat, 2002). In the southern Weddell Sea only weak anomalies were detected. A zoomed map of the region marked by a blue box can be found in Fig. 2, FRSCT (Filchner-Ronne Shelf Crustal Transect) is the baseline on which all the stations have been projected. Abbreviations: ANT-Antarctica, AFR: Africa, AP: Antarctic Peninsula, AUS: Australia, BI: Berkner Island, CA: Central Anomaly, COB: Continent-ocean boundary, DM: Dufek Massive, EA: Explora Anomaly, EE: Explora Escarpment, EWM: Ellsworth-Withmore Mountains block, GP: Grunehogna Province, NY: New Zealand, PAZ: Pacific Ocean, PB: Polarstern Bank, SAM: South America, SP: Scotia Plate, TI: Thurston Island Block, WS: Weddell Sea. b: Kinematic sketches for early opening of the Weddell Sea (modified after König and Jokat, 2006). Upper panel: position of the continents at the rift/drift transition (168 Myr). The thick red arrow in both panels marks the likely drift of the EWM according to Dalziel and Grunow (1992) and Grunow (1993). Lower panel: position of the continents in the Late Jurassic (147 Ma). The hatched area shows the area where the volcanic rocks forming parts of the Mozambique Ridge erupted. The black arrows in the Weddell Sea indicate the spreading direction. The different on-/offshore volcanic units/outcrops are marked in green and read. Major dyke swarms in southern Africa are drawn by black lines (Limpopo dyke swarm). The dotted line between magnetic anomalies in the Kirvanweggen and the Beattie Magnetic anomaly indicate a possible structural link, which is used for the initial fit between Africa and East Antarctica. The light blue line indicates the position of the Filchner Ronne Crustal Transect (FRSCT). The red lines just north of the FRSCT mark the weak but continuous magnetic anomalies below the Filchner Ronne Shelf. Otherwise the thin blue and red lines indicate the size of the different plates as used for this sketch. Cratons are drawn in yellow. Abbreviations: Beattie-A: Beattie Magnetic anomaly, FKI: Falkland Islands, IND: India, MAD: Madagascar, MBL: Marie Byrd Land, MEB: Morris Ewing Bank, MOZB: Mozambique Basin, MOZR: Mozambique Ridge, RLS: Riiser Larsen Sea, SDRS: Seaward dipping reflectors, SRI: Sri Lanka, otherwise like in Panel a.