Crustal types and continent-ocean boundaries between the Kerguelen Plateau and Prydz Bay, East Antarctica

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Summary Cretaceous Gondwana breakup between East Antarctica and India was accompanied or followed by emplacement of the Kerguelen Plateau Large Igneous Province (LIP), north of Prydz Bay. In 2007, deep crustal seismic and helicopter-magnetic surveys were conducted along a corridor between the southern Kerguelen Plateau and the outermost Prydz Bay. These surveys were designed to investigate breakup processes and the effect that the igneous activity had on the formation of the passive margin of East Antarctica and also the apparent oceanic crust between the plateau and the Antarctic margin in the Princess Elizabeth Trough (PET). Preliminary data analysis and modeling reveal a wide zone of highly extended continental crust on the margin of Mac.Robertson Land and that the southernmost Kerguelen Plateau is generally of continental affinity. Seismic velocities and magnetic data indicate an oceanic-type crust beneath the PET. Magmatic accretion to this crust from the Kerguelen LIP is widely observed.

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Introduction and significance

The separation of Greater India from Antarctica in the Early Cretaceous and the breakup of Australia from Antarctica since the Late Cretaceous led to the formation of the modern Indian Ocean and a continuous oceanic passage between the southern Atlantic (Weddell Sea), the Southern Indian Ocean and the western Pacific. The Cretaceous Gondwana break-up was accompanied by enormous volcanic extrusions of so-called Large Igneous Provinces (LIP), such as the Kerguelen Plateau in the Southern Indian Ocean. The Kerguelen Plateau marks one of the two most voluminous LIPs in an oceanic setting and is attributed to the Kerguelen mantle hotspot emplaced at 120 Ma ago, about 15 m.y. after the onset of seafloor spreading between India and Antarctica (Gaina et al., in press). Earlier studies and ODP Leg 183 drill data have shown that the Southern Kerguelen Plateau and Elan Bank are partly underlain by continental crust affected by Cretaceous extension (e.g. Operto & Charvis, 1996; Gladczenko & Coffin, 2001). It is unclear how far south the plateau maintains possible continental origin and how its igneous activity affected the apparent oceanic crust of the Princess Elizabeth Trough between the plateau and the East Antarctic continent. On the Antarctic margin, Prydz Bay lies at the offshore continuation of the Lambert Graben that marks one of the most prominent intracontinental rifts. The aims of the deep crustal seismic and magnetic surveying project described here were to investigate: (a) the structural parameters, physical properties and inter-relations of rifted continental, oceanic and volcanic crust in the greater Prydz Bay area; (b) the mechanism of extension of continental crust, geometry of rifting and time of rifting stage; (c) the position and nature of the continent-to-ocean transition, and the timing and geodynamic regime of seafloor formation; (d) the subsidence history of the Cooperation Sea basin and its evolution as a deep oceanic gateway; and (e) the tectonic nature of the southern Kerguelen Plateau (oceanic edifice or continental sliver) and the relationship between seafloor spreading and LIP formation.

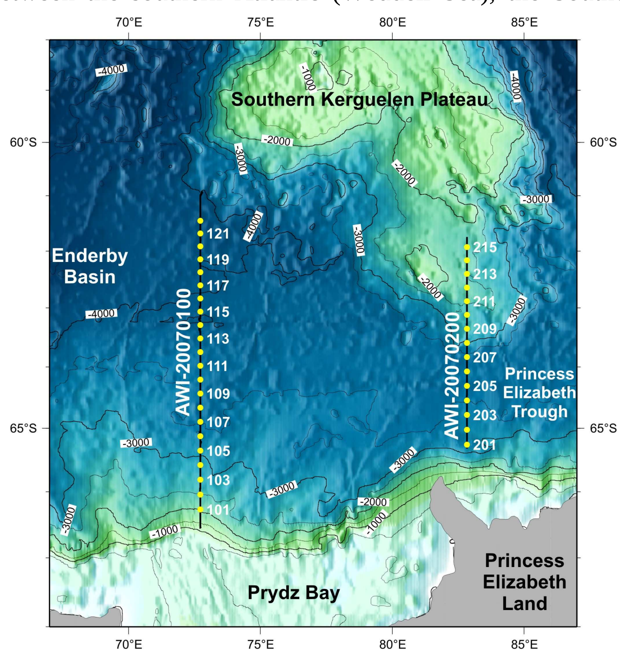

Figure 1. Topographic map of study area with OBS/OBH stations (yellow dots and station numbers) along deep crustal seismic profiles (black lines).

In early 2007, we addressed these objectives with deep crustal seismic profiling, using ocean-bottom seismographs (OBS; Figure 1), and shipborne and helicopter-magnetic surveying in cooperation between Alfred Wegener Institute for Polar and Marine Research (AWI), with RV *Polarstern* during expedition ANT-XXIII/9, and VNIIOkeangeologia and Polar Marine Geological Expedition (PMGE), with the RV *Akademik Alexander Karpinsky* during the 52th Russian Antarctic Expedition. The presence of the two ships further allowed a two-ship seismic wide-angle reflection experiment.

First results and tectonic implications

Intermediate to good quality refraction and wide-angle reflection data with source-receiver offsets up to 70 km were recorded by 21 OBS systems across the eastern Enderby Basin along profile AWI-20070100 (Figure 1). This deep crustal seismic dataset includes refracted P-wave phases from at least two sedimentary layers and at least two layers of the crystalline crust. Reflection phases from the crust-mantle boundary are observed on five recordings. Ten recordings show a low-amplitude refracted phase from the upper mantle. We derived a first velocity-depth model using a standard raytracing/travel-time inversion routine and a first-arrival travel-time tomography. In the resulting preliminary model (Figure 2), sediment velocities were modelled with 1.8 – 2.8 km/s for the upper sediment layer and 2.4 – 4.2 km/s for second sediment layer. The upper sediment layer has an almost uniform thickness of about 1 km along the profile, whereas the second layer is thin on the northern part of the profile and thickens distinctively towards the south reaching a thickness of more than 4 km. The crust beneath the top of the acoustic basement, with its top boundary taken from coincident seismic reflection profiling acquired by RV *Karpinsky*, shows significant lateral variations in the P-wave velocity from 5.5 – 6.5 km/s in the northern half of the profile to 5.0 – 6.0 km/s in the southern half. The velocities in the middle and lower crust range from 6.2 km/s at the top to 7.6 km/s at the base. They exhibit less lateral variations but also decrease to the south. The Moho depth increases from about 14 km at the northern end of the profile to about 16 km in the south. By subtracting the water column, these depths correspond to crustal thicknesses between 10 km in the north and 13 km in the south. P-wave velocities of the uppermost mantle are modelled with 8 km/s.

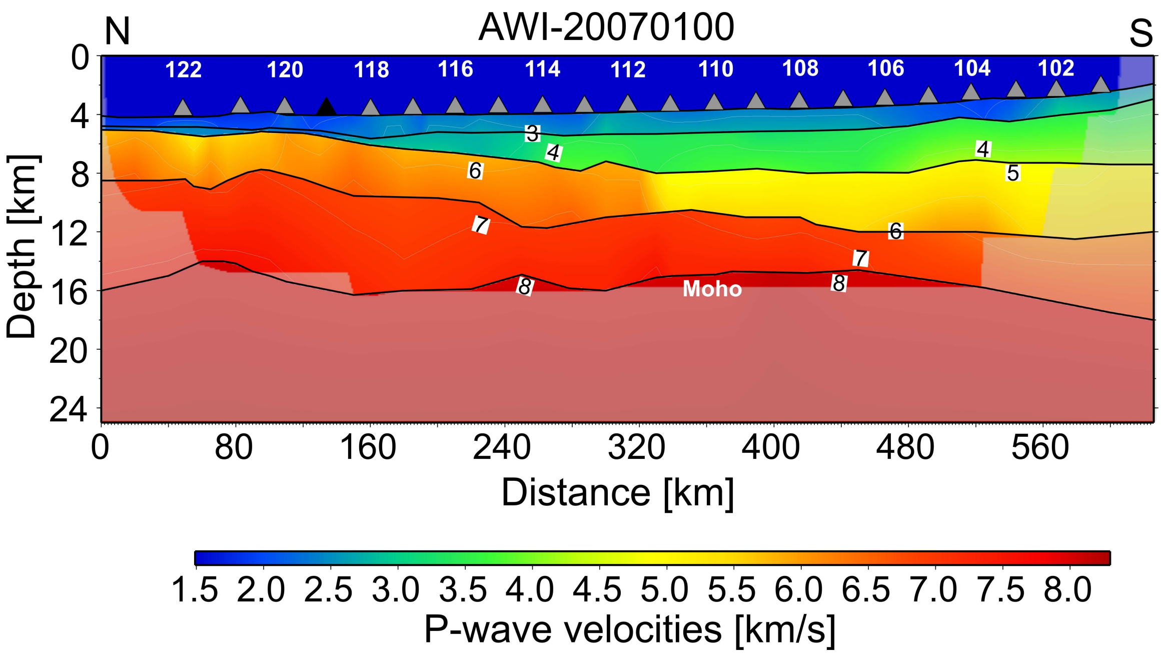

Figure 2. Preliminary P-wave velocity-depth model of profile AWI-20070100.

This profile is located on the crust of the eastern Enderby Basin between the foot of the continental slope and an area just off the southwestern edge of the Kerguelen Plateau (Figure 1). While the crustal thickness remains almost constant along the profile, we observe a distinct, almost abrupt change in mid-crustal seismic P-wave velocities and a smoother change in velocity in the lower crust in the center of the profile. The bulk mid-crustal velocities in the southern part of the profile correspond to those of intermediate to felsic composition, thus, continental origin. Areas of low velocities in the acoustic basement may indicate pre- or synrift sediments. The P-wave velocities of the northern profile half are interpreted to originate from a layer of oceanic crustal composition. The mid-crustal velocity change coincides with the location of the Mac.Robertson Coast Anomaly (MCA) (Stagg et al., 2005; Gaina et al., in press) and with a major change in the seismic reflection character of the crust (Stagg et al., 2004) which has been suggested to mark the continent-ocean boundary. A more detailed analysis of the data in the months to follow will include the S-wave arrivals and the data of the wide-angle two-ship experiment as well as the magnetic and gravity survey. However, if this first analysis and interpretation can be confirmed, the rifted continental margin of Mac. Robertson Land underwent enormous crustal thinning before breakup from India or the continental fragments of the Kerguelen Plateau.

The records of the 15 OBS systems across the Princess Elizabeth Trough and onto the Southern Kerguelen Plateau along profile AWI-20070200 (Figure 1) exhibit a significantly better data quality than those of the western profile. Nine recordings show refracted P-wave phases from the upper mantle (P_n) at source-receiver offsets up to 85 km. P_n phases of records from the northern stations arrive are offset in time to the first-arrival travel-time branches by more than a second, indicating a possible low-velocity zone in the crust. A first raytracing and inversion model was calculated using P-wave arrivals of all 15 stations and with the basement being identified from the coincident Russian seismic reflection line RAE-3910 (Figure 3). The upper sediment layer can be modelled with velocities between 1.8 and 2.5 km/s while velocities between 2.5 and 4.4 km/s are modelled for the second sediment layer. Basement highs separate the sedimentary section into four sub-basins. The thickness of the sediments increases from 1.5 km in the north to 3.5 km in the south. The upper crustal velocities range from 4.2 to 6.4 km/s. The thickness of upper crystalline crust is about 4 km, except for the basement highs where it is about 5 km thick. The thickness of the lower crust decreases from 10 km in the north to 4 km in the south. Its velocities vary in the south from 6.3 km/s at the top of this layer to 7.6 km/s at the base of the crust. In the north, the lower two-thirds of the lower crust consist of a low-velocity zone with velocities between 6.5 and 6.9 km/s. The Moho depth decreases from about 17 km in the north to 14 km in the south. The uppermost mantle has velocities of about 8 km/s. It must be noted that, in particular, the velocity structure of the lower crust is still very preliminary and needs to be verified by further analysis.

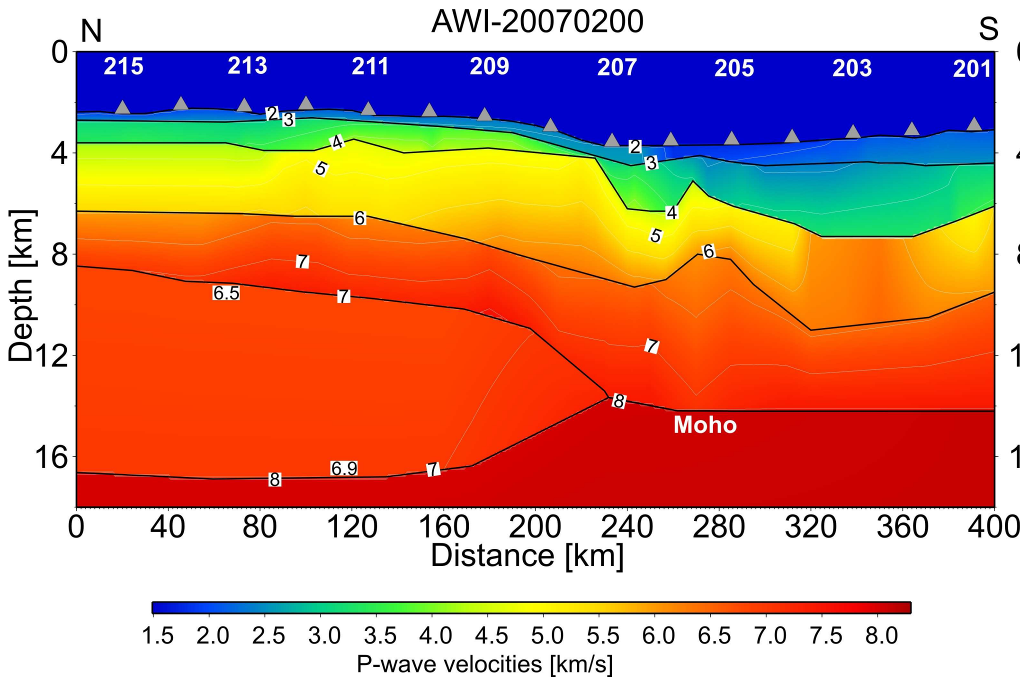

Figure 3. Preliminary P-wave velocity-depth model of profile AWI-20070200.

These preliminary results of the velocity-depth model are dominated by the structure of the Southern Kerguelen Plateau to the north. The vertical crustal velocity distribution changes from the thick crust of the plateau to that of the thin oceanic crust beneath the Princess Elizabeth Trough. The P-wave data from the plateau indicate that a good portion of the lower crust consists of low-velocity continental-type rock composition. This means that the partial continental affinity of the Southern Kerguelen Plateau, as indicated by seismic data and ODP drill samples further north (e.g. Operto & Charvis, 1996; Gladczenko & Coffin, 2001), continues to the southernmost limit of the plateau. Here, the continental crust must have been enormously thinned and fragmented as part of the rifting process between India and Antarctica. Later, with the onset of the Kerguelen hotspot activity, this region was subject to accretion and extrusion of voluminous amounts of igneous material from the mantle, including parts of the oceanic crustal Princess Elizabeth Trough. However, more detailed data analyses have to be performed by integrating S-wave phases of the OBS recordings, pre-existing regional seismic reflection lines, and magnetic and gravity survey data.

The gridded helicopter-magnetic data as well as the amplitude wiggle-track plots (Figure 4) show clear several linear trends in the surveyed swaths. The southern half of the magnetic anomaly swath along profile AWI-20070100 exhibits very low amplitude anomalies without any distinct pattern. The middle of the profile is characterized by the dominant positive Mac.Robertson Coast Anomaly (MCA) which has been well observed through the Enderby Basin (Gaina et al., in press). North of the MCA, a pattern of east-west trending anomalies appears which have been modelled in detail to derive a crustal age and structural model. The swath data along profile AWI-20070200 show linear anomaly trends in an east–west direction, changing to a northwest strike direction in the north where the profile crosses the southernmost Kerguelen Plateau. As our seismic data on this profile indicate fragmented continental crust under the southern Kerguelen Plateau, we tried to fit only the southern part of the profile to seafloor spreading anomalies within the isochron range of M11 to M2 (about 137.0 - 127.5 Ma) according to a previously published age model for this part of the crust (Gaina et al., in press). By assuming that there must be a former spreading center in the Princess Elizabeth Trough if the Kerguelen Plateau is continental, and that the trough is oceanic (as suggested from our seismic model), we found the best fit of synthetic data to the observed magnetic profile data between chrons M6 and M10 on both sides of an extinct spreading center. Such a spreading center is also indicated at this position in an older seismic reflection data profile.

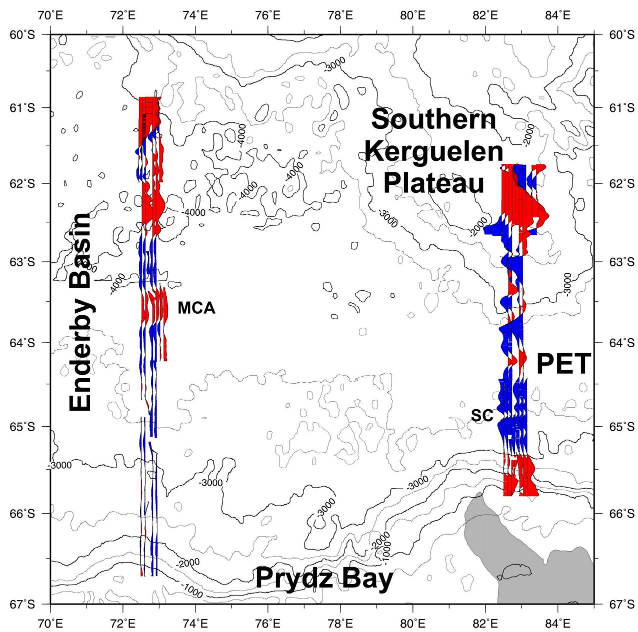

Figure 4. Map with amplitude wiggle-tracks of the heli-magnetic surveys parallel to profiles AWI-20070100 (west) and AWI-20070200 (east). Negative amplitudes of total intensity anomalies are in blue and positive amplitudes are in red. Data are unlevelled. PET = Princess Elizabeth Trough, MCA = Mac. Robertson Coast Anomaly, SC = former spreading

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