seismic anisotropy - receiver functions - dronning maud land / antarctica

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introduction

By analysis of shear wave splitting and calculation of receiver functions, we applied two common seismological methods to derive detailed information about the earth's interior and geological structures of Dronning Maud Land (DML), Antarctica.

Previous studies of shear wave splitting from seismograms recorded at the German Polar Research Station Neumayer show a two-layer subsurface model that fits the apparent splitting parameter sufficiently well. This is not the case for measurements made at the South African station SANAE IV (SNAA) because even for narrow backazimuthal segments the (apparent) splitting parameters and receiver functions show strong variations. Hence, a much more complicated (anisotropic) subsurface structure seems likely and the strong variations have to be interpreted in terms of the region's complicated history.

Furthermore, we introduce results from temporary seismometer deployements. During several polar expeditions in the years 2000 until 2004, seismometers were situated in primarily ice free regions along mountain ranges such as Heimefront shear zone with Kottas Mountains in western DML, Wohlthat Massif, and on the Russian station Novolazarevskaja (NOVO), both in central DML.

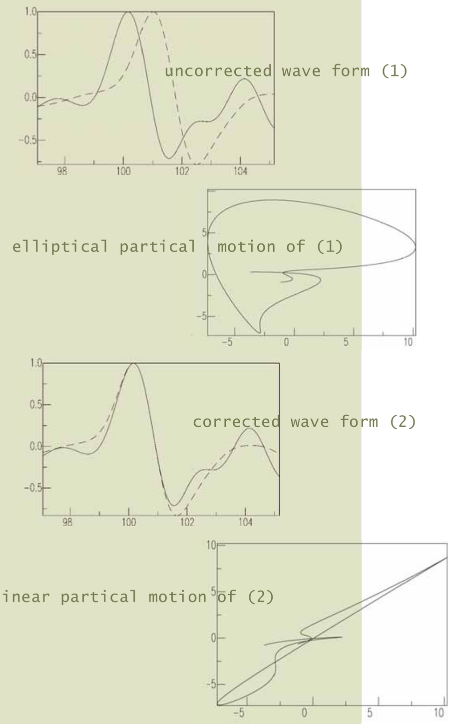
splitting measurement

The general idea of measuring the splitting parameters, time delay δt and fast polarisation direction Φ, is to un-split the generated shear wave. [Silver & Chan, 1991] developed a method that estimates the splitting parameter by minimizing the energy on the transverse T-component.

For our investigations individual splitting measurements of generated SK(K)S and S(cS) phases were only taken into account when

(1) there was a clear correlation between the waveforms of fast and slow component,
(2) a clear elliptical partical motion of the uncorrected waveform was observed,
(3) the partical motion after correction was linear,
(4) the energy of the transverse component was removed after correction,
(5) the SNR between the wavelets were significant high.

Figures on the right hand side show a SKS phase registration recorded on station SNAA. It demonstrates the un-spliting process: Before correction, energy of the transverse component leads to an elliptical partical motion. After correction, the observed partical motion is linear. Both horizontal waveforms have a similar shape.



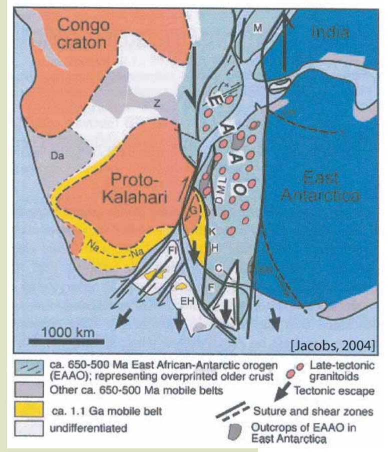
geology & tectonic

Several geological and tectonic events during earth's history formed the present-day Antarctic continent. Within the area of investigation, Dronning Maud Land (DML), outcrops were formed during several phases:

(1) The Grenville, at 1.1 Ga, during building of the supercontinent Rodinia.

(2) The Ross-/Panafrican, at 500 Ma, during building of the supercontinent Gondwana and due to collision between West and East Gondwana.

(3) The break-up of Gondwana at 180 Ma started in the Weddell Sea (the oceanic area off DML) and was accompanied by voluminous volcanism, magmatism, and major outpourings of continental flood basalts [Jacobs, 1998]. The initial break-up took place in two-stages [Cox, 1992]. During the first stage, an old Permo-Triassic shear zone was reactivated so that Africa and Antarctica moved apart along NE-striking left lateral transform fault. During stage two seafloor spreading started and the two continents drifted away in NNW-SSE direction.

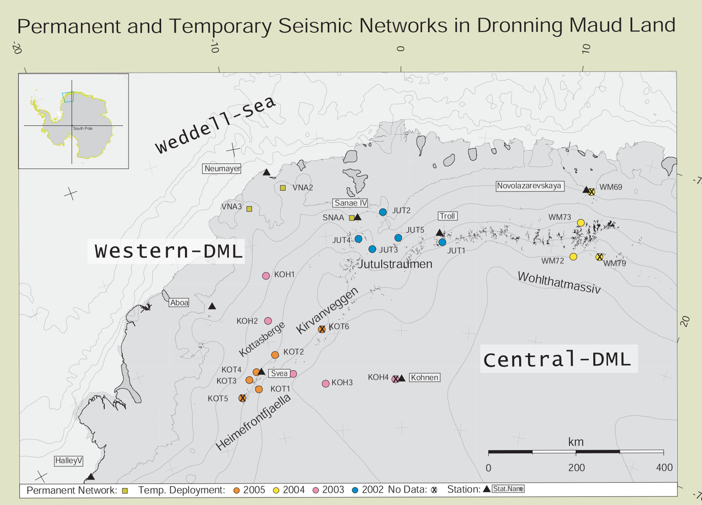


The present-day ice coverage of the continent makes it difficult to map these geological structures in detail. But with our investigations, we are able to draw conclusions about the existence of separate regions with different structure.

Figure right: These cartoon after [Jacobs, 2004] demonstrates the collision of East and West Gondwana 500 Ma years ago and the break-up of Gondwana. Within the DML the Zimbabwe-Kaapvaal-Grunehogna Kraton (G) is located.

area of investigation

Within several polar-summer expeditions, seismological stations (REFTEK-130 data acquisition storage systems in combination with Lennartz 5s or 20s seismometer) were deployed along the mountain range in western DML (wDML) and central DML (cDML). Duration of recordings varied between 3 weeks and 7 month. For seismological station SNAA registrations of the years 2002 until 2005 were taken into account.



heimefront shear zone

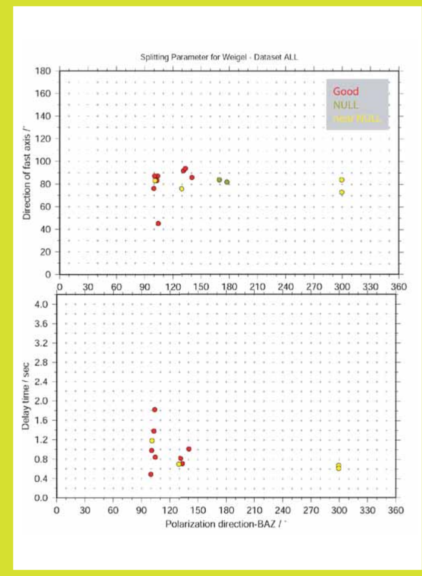
Observation from seismographs across Heimefront shear zone:

(1) One anisotropic layer explains the observed splitting parameter sufficiently well

(2) No backazimuthal variability of the splitting parameter was found

Conclusion:
Crust and upper mantle were coherently deformed during orogenies: Vertical Coherent Deformation [Silver, 1996]). This is well supported by the comparison of anisotropy and the magnetic small-scalled anomaly field: Fast axis are parallel to the magnetic anomalies.

1. observed splitting parameters



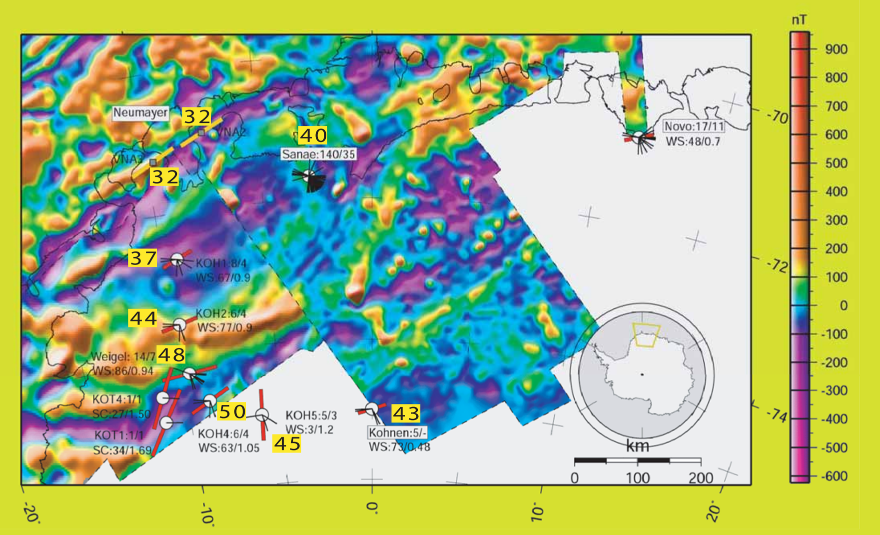
A four month lasting recording of temporary deployed seismic station on Weigel Nunatak yielded a wide backazimuthal coverage of detected core shear phases. Best fitting splitting parameters calculated with the stacking method of [Wolfe&Silver, 1998] were determined to:

Fast pol. axis: 86.0 +/- 5°
Time delay: 0.94 +/- 0,25s

Note the strong time delay variation for events with backazimuth of ~90° (bottom graph). This is due to instability of the calculation's allgorithm for phases with backazimuth parallel (or perpendicular) to the fast polarization axis. Clear NULLS were observed for events from Vanuatu and Solomon Islands. These events remain unsplitted because their seismic waves travel through the medium in an orthogonal direction respective to the fast polarization axis.

figure: backazimuth vs observed splitting parameters. upper: fast axis, lower: time delay

2. magnetic anomalies & anisotropy & moho depth (after hoffmann, 2002)



Registrations of Kottas Mountains (KOT) and across the Heimefront shear zone (KOH) show that directions of the fast axis (red bars) are subparallel to small-scale magnetic anomalies [EMAGE magnetic grid, 2002]. This is interpreted as vertical coherent deformation of the crust and upper mantle during orogenies in the past.

For the investigation of the crustal thickness with receiver functions different data sets were used [Hoffmann, pers. comm.]. Seismological and seismic surveys in wDML provided the data for obtaining the moho depth (black numbers [km] with yellow background). It is obvious, that the crustal thickness increases across the Heimefront shear zone and reaches there its maximum depth.

All used events are denoted with black thin bars represented by the events' backazimuths. WS means calculation after [Wolfe&Silver, 1998], SC means calculation after [Silver&Chan,1991] for individual single events. Lengths of red bars represent the time delay, direction the azimuth of the fast axis.

figure: splitting parameters in comparison with magnetic anomalies and crustal thickness

russian station novo

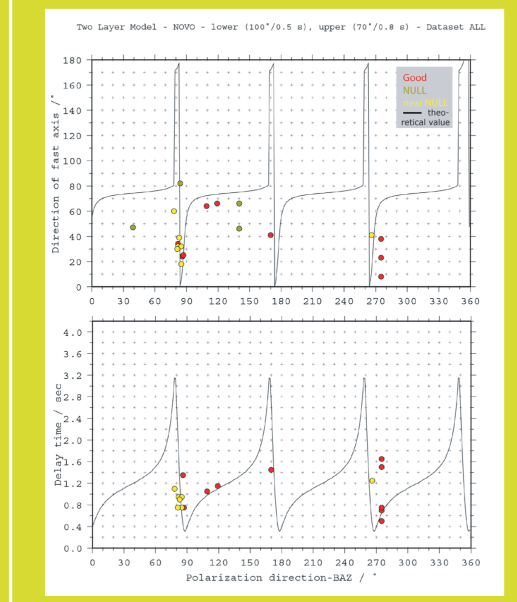
Observation for Russian station Novo:

(1) Two anisotropic layers explain the observed splitting parameter sufficiently well

(2) Fast axis of the upper layer is parallel to the mountain strike of Wohlthatmassif, fast axis of the lower follows the passive continental margin (CM)

Conclusion:
Because the station is located on the East Antarctic Craton (EAC) and very close to the passive CM, we suggest that the upper layer relates to the lithosphere of EAC, whereas the lower layer represents a kind of anisotropic remnant reservoir that was build up during the inital break-up of Gondwana.

1. splitting parameters & 2-layer-model



A seven month lasting registration of the temporary deployed seismograph at Novo yielded a wide backazimuthal coverage of detected core shear phases. A two-layer modeling after [Savage& Silver,1993] show best fitting splitting parameters for two anisotropic layers:

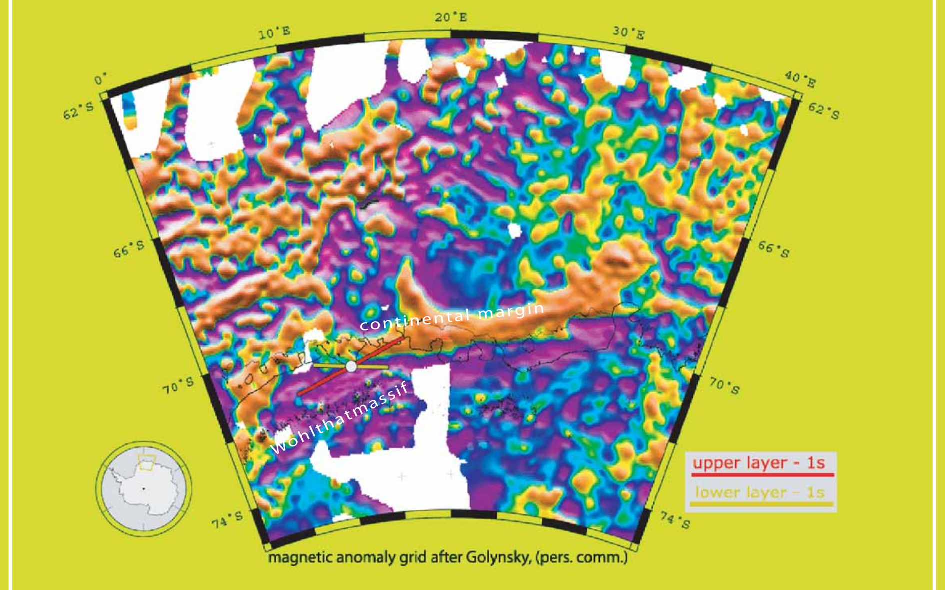
Upper layer:
Fast pol. axis: 70.0°
Time delay: 0.80s

Lower layer:
Fast pol. axis: 100°
Time delay: 0.50s

Observed splitting parameter (dots) follows the theoretical ones (solid lines) relatively close. The characteristic 90° periodicity of the splitting parameters for the case of a two-layer model is well constrained.

figure: backazimuth vs observed splitting parameters. upper: fast axis, lower: time delay

2. magnetic anomalies & anisotropy



Fast axis of the upper layer tends to be parallel to the mountain strike of Wohlthatmassif, an orogeny that is aligned to the continental margin. The upper mantle olivine a-axis were aligned through vertical coherent deformation during the Kibarian Orogeny (1.1 Ga) or the Pan-African overprinting (500 Ma).

Fast axis of the lower layer follows the passive continental margin that was re-built during Gondwana break-up at Late Jurassic.

Because the break-up was the last major tectonic event in the continentals history it is obvious to relate the lower layer to them as a remnant anisotropic deposit of frozen mantle material.

figure: splitting parameter in comparison with magnetic anomalies

southafrican sanae

Observation for South African station SNAA:

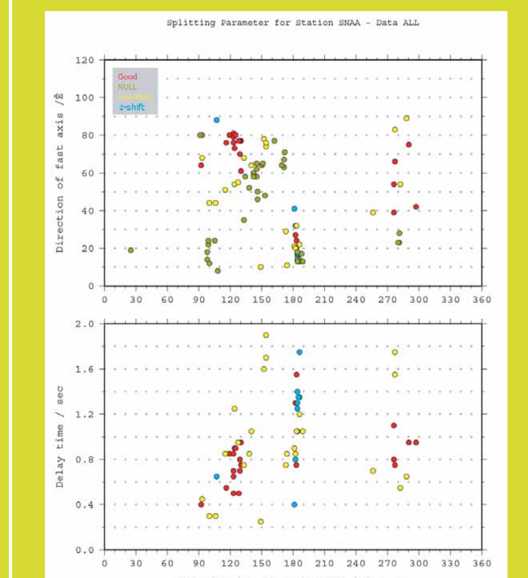
(1) Most detected phases show clear NULL measurements

(2) For narrow backazimuth segments the splitting parameters and receiver functions show strong variations

(3) All SK(K)S phases from Fiji Islands show clear energy on the vertical component

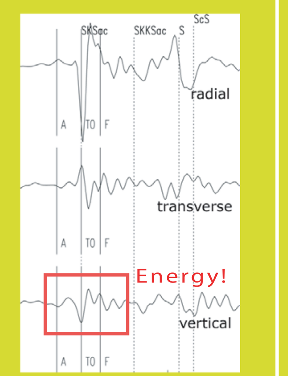
Conclusion:
The observed splitting values could not be explained by a one- or two-layer anisotropic model. A much more complicated must be assumed.

1. splitting parameters



Registrations of the years 2002 until 2005 were investigated.

1. Neither a clear distribution nor a typical periodicity of the splitting values were found. The bulk of investigated phases show clear NULLS and pretends therefore an isotropic medium.

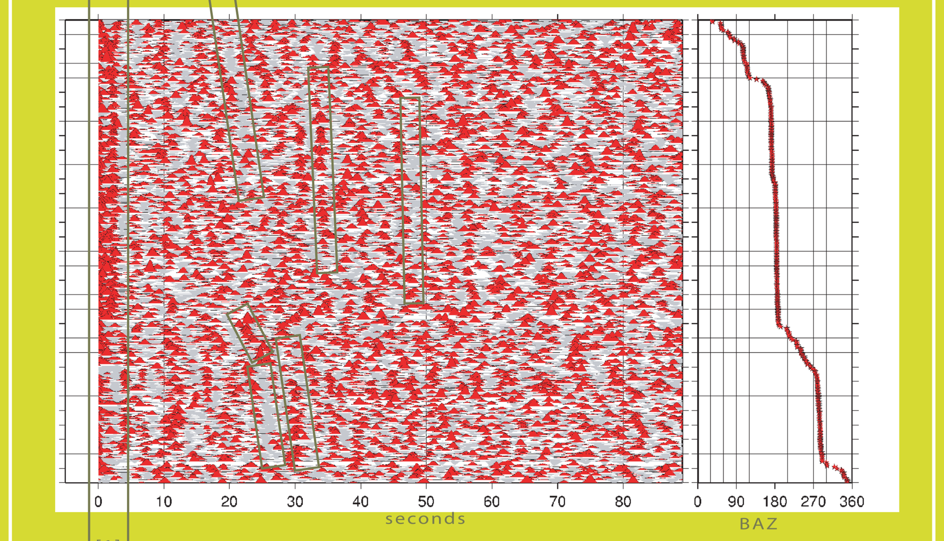


2. All shear phases, generated by earthquakes from Fiji Island Region (BAZ ca. 180°, light blue dots), show energy on the vertical component (figure right). This is unusual for SK(K)S phases.

3. Also for narrow backazimuthal segments, splitting parameter show strong variations. NULL and those measurements, which detect anisotropy, are lying close together and overlap in terms of the backazimuth.

figures: backazimuth vs observed splitting parameters | seismogram of Fiji quake.

2. transversal receiver functions
(after m. hoffmann, 2006)



Transversal receiver functions showing clear energy. This indicates layers with strong inhomogenities, dipping layers and/or complex anisotropic behaviour.

Section [1] indicates signals from intra-crustal layers.

Moho depth beneath the station was determined to 40 km.

figure: transversal receiver functions

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