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A mechanism for construction of volcanic rifted margins during continental break-up

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In the accompanying paper[1], we conclude that SDRs do not result from collapse of a sub-aerial mid-oceanic ridge but are instead formed at the final stage of continental break-up when normal faulting and magmatic accretion operate together. Mafic melt derived from the asthenosphere rises beneath the margins of an axial horst to form a magma chamber from which tholeiitic basalts are sourced, erupting as sub-aerial flows into the accommodation space on the sides of the horst. With continued fault growth, the flows become seaward-tilted due to roll-over whilst gabbro is accreted on the flanks of the magma chamber beneath the horst. Here we present extended information in the form of depth and thickness maps, 3-D images of the crust, and additional seismic sections supporting the interpretations. Associated references and acknowledgements are also included.

[1] Geology, December 2014.

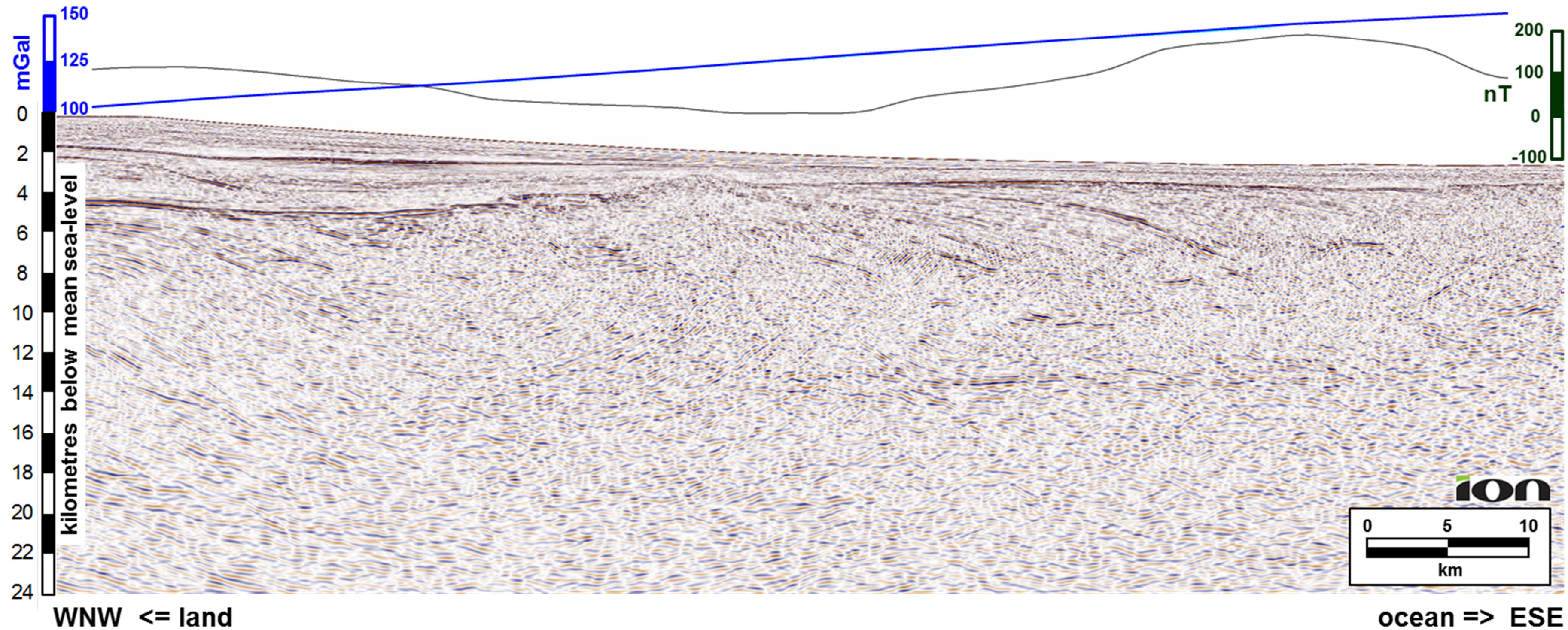


Figure DR1. Uninterpreted 2D PreSDM seismic section from East Greenland at 1:1 horizontal to vertical scale. Profiles above seismic section are Bouguer gravity (blue line) and magnetic anomaly (black line) from Andersen et al. (2010) and Maus et al. (2009), respectively. This is the same section as Fig.2 in the accompanying paper. For further information concerning the acquisition and processing of these data, the reader is referred to Granath et al. (2010) and Dinkelman et al. (2010)

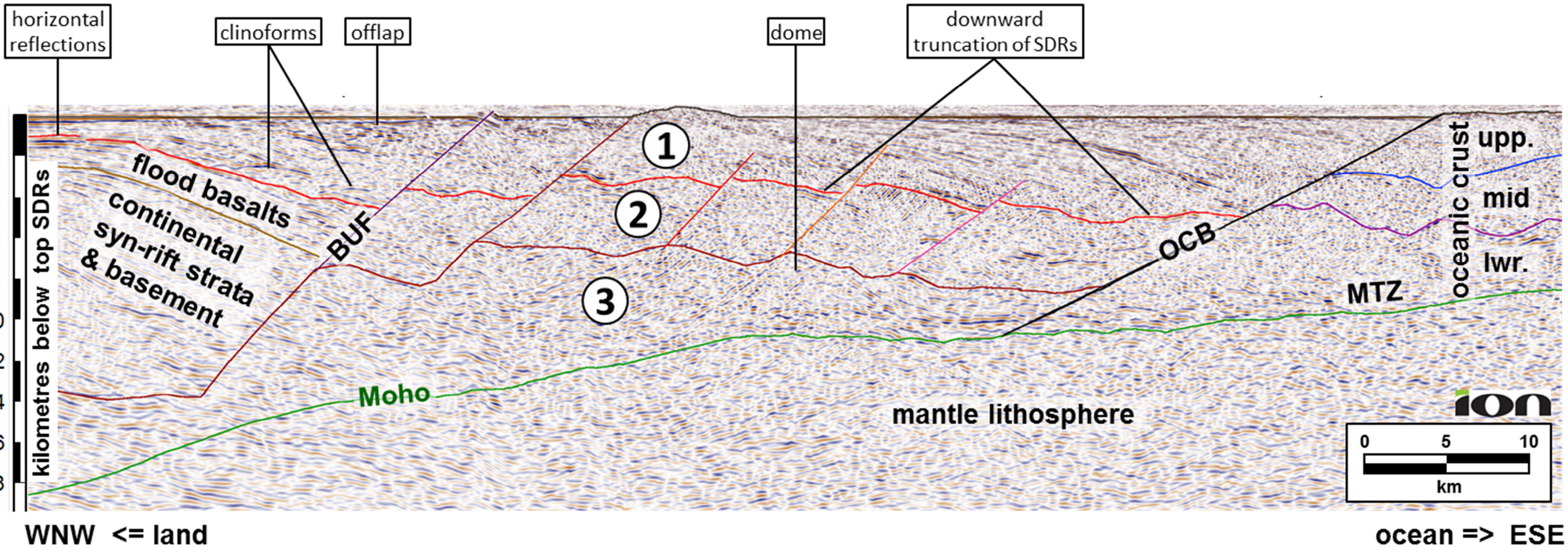


Figure DR2. Same 2D PreSDM seismic section as shown in GSADR Fig.1 but flattened on top SDR horizon to emphasize syn-tectonic geometries. 1 - SDRs (sub-aerial basalt lava flows). A volcano is visible above 1, probably originally located along the edge of the axial horst but stranded in the hangingwall as a new normal fault formed on its seaward side. 2 - mid-crust imbricate layer (sheared gabbro). 3 - lower crust mobile layer (cumulates and sills of mafic and ultramafic rocks). BUF - break-up fault. OCB - oceanic crust boundary. Other landward-dipping dipping faults are also shown (coloured lines). MTZ - Moho transition zone.

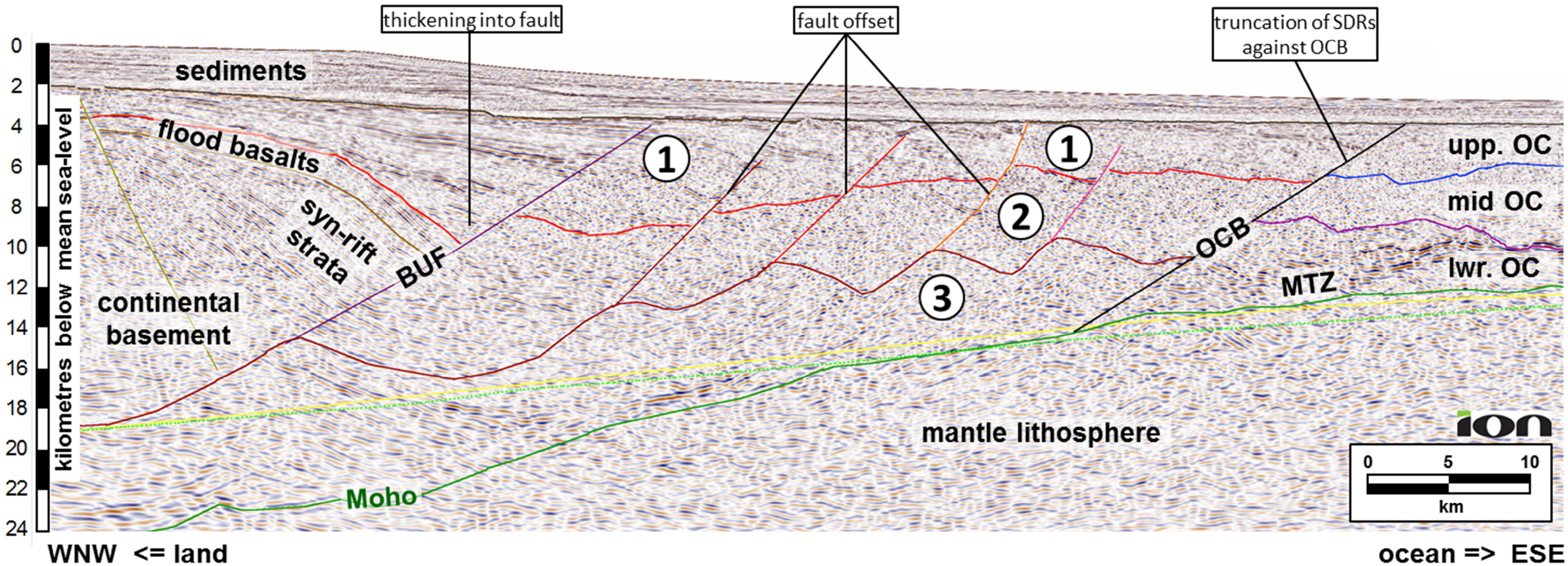
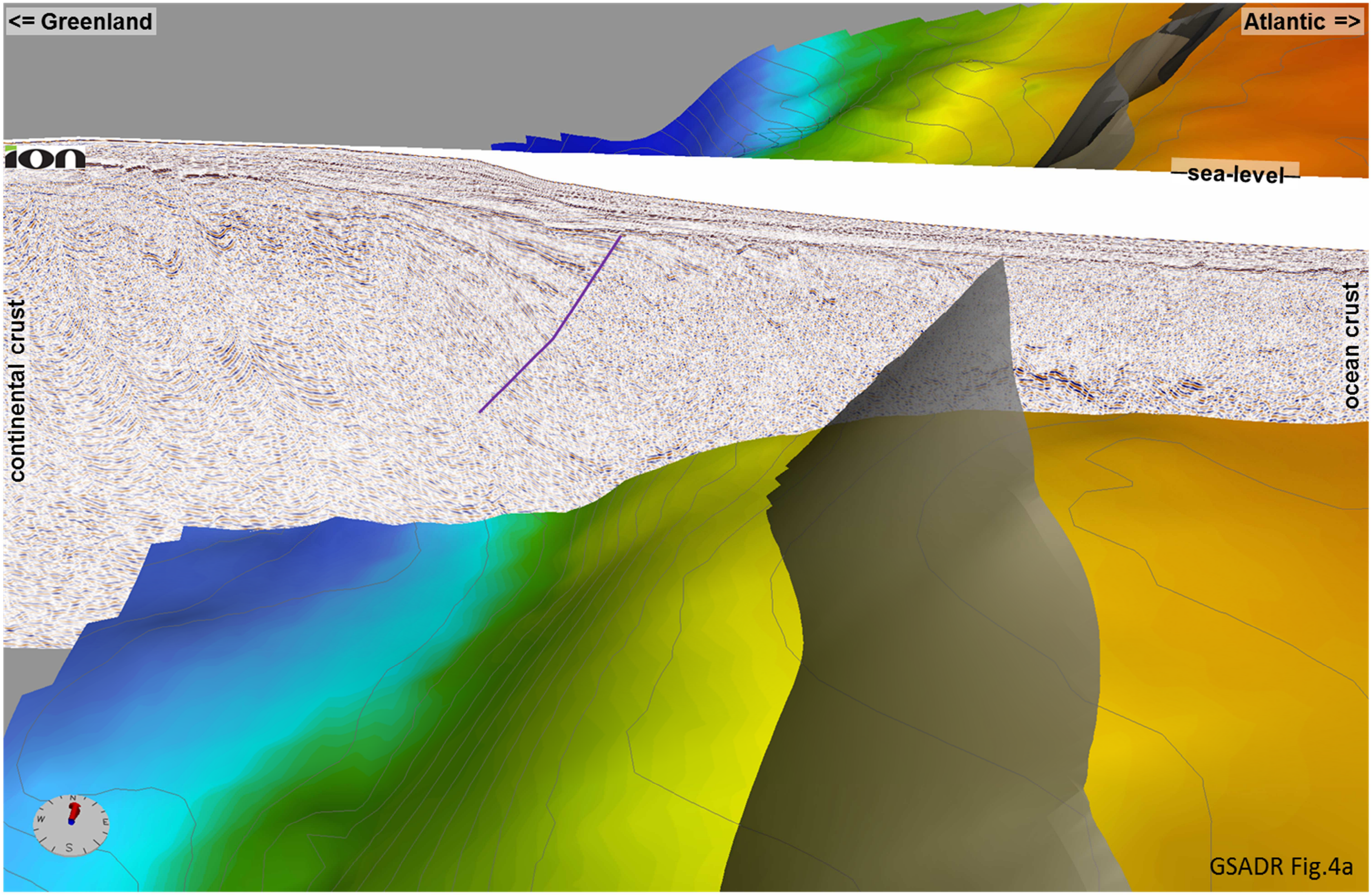


Figure DR3. 2D PreSDM seismic section from East Greenland at 1:1 horizontal:vertical scale showing mapped horizons and key features of SDR-bearing transitional crust. An uninterpreted version of the line is displayed in GSADR Fig.4. Stippled green horizon - base crust interpretation from refraction seismic model above which seismic refraction velocities are modelled to be 7150-7400 $m.s^{-1}$ (Voss et al., 2009). Yellow horizon - 7500 $m.s^{-1}$ interval velocity from PreSDM model (Granath et al., 2010). 1 - SDRs (sub-aerial basalt lava flows). 2 - mid-crust imbricate layer (sheared gabbro). 3 - lower crust mobile layer (cumulates and sills of mafic and ultramafic rocks). BUF - break-up fault. OCB - oceanic crust boundary. Other landward-dipping dipping faults are also shown (coloured lines). MTZ - Moho transition zone. OC - oceanic crust (upp. - upper; lwr. - lower).


<= Greenland
Atlantic =>
ion
sea-level
continental crust
ocean crust
N
W
E
S
GSADR Fig.4a

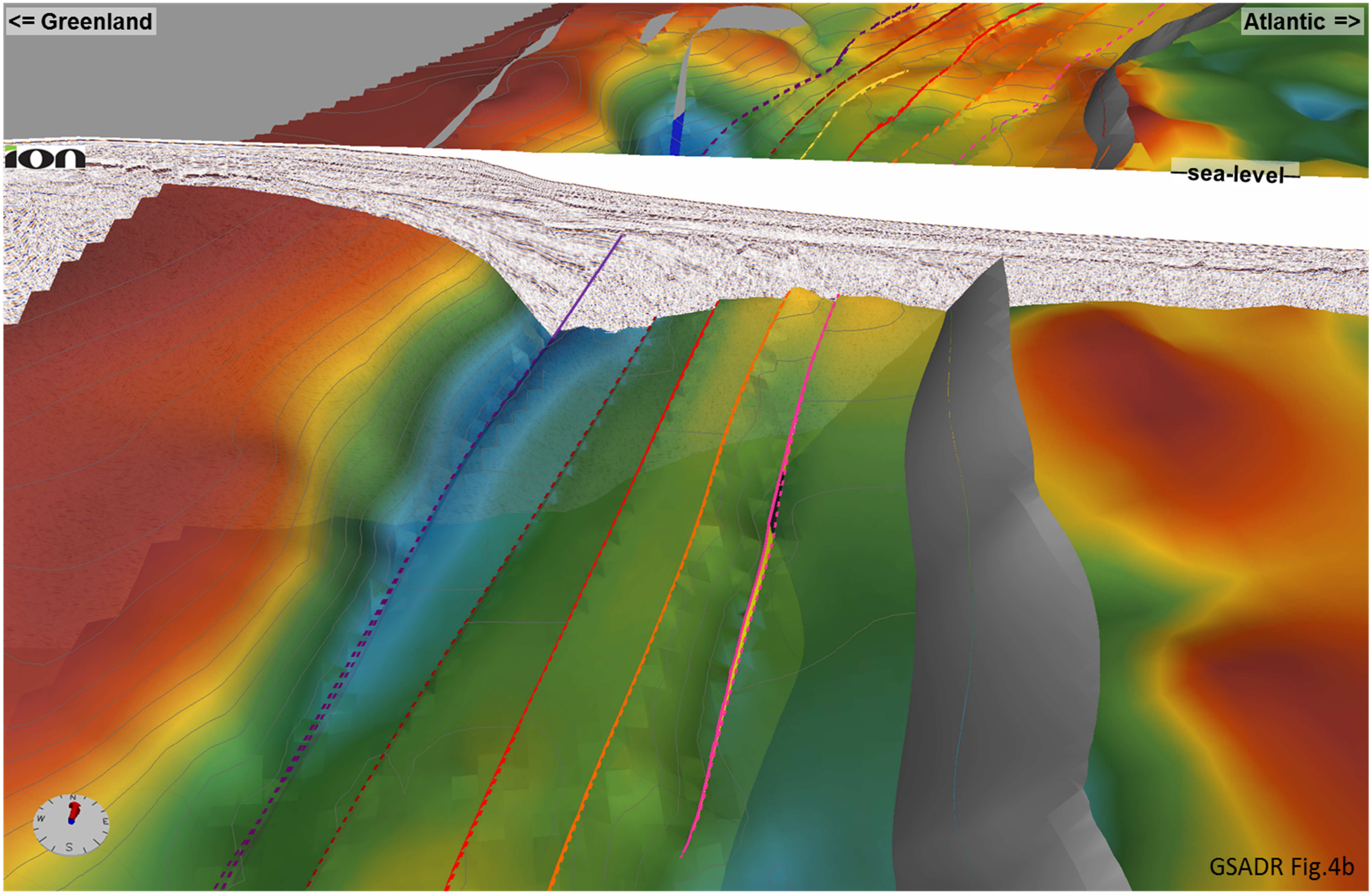

<= Greenland
Atlantic =>
ion
sea-level
N
W
E
S
GSADR Fig.4b

Figure DR4. 3-D view of East Greenland crust looking north with representative PreSDM seismic section (uninterpreted version of GSADR Fig.3, field of view 140 km long by 40 km deep). The inclined grey surface is OCB expressed as a landward-dipping low angle normal fault. The break-up fault is shown with purple line.

a) Moho depth surface with depth contours every 1000 m (shading is Bouguer gravity anomaly: blue - low; orange - high).

b) Same view as a) with addition of base SDR depth surface (west of OCB) and base upper oceanic crust (east of OCB). The contours on the base SDR depth surface are 500 m intervals, reaching a total depth of 10 km below sea-level. Shading also indicates depth on both base SDRs and base upper oceanic crust (blue - deep; red - shallow). Coloured lines on the base SDR depth surface represent normal faults which were abandoned at times when the axial horst jumped oceanwards.

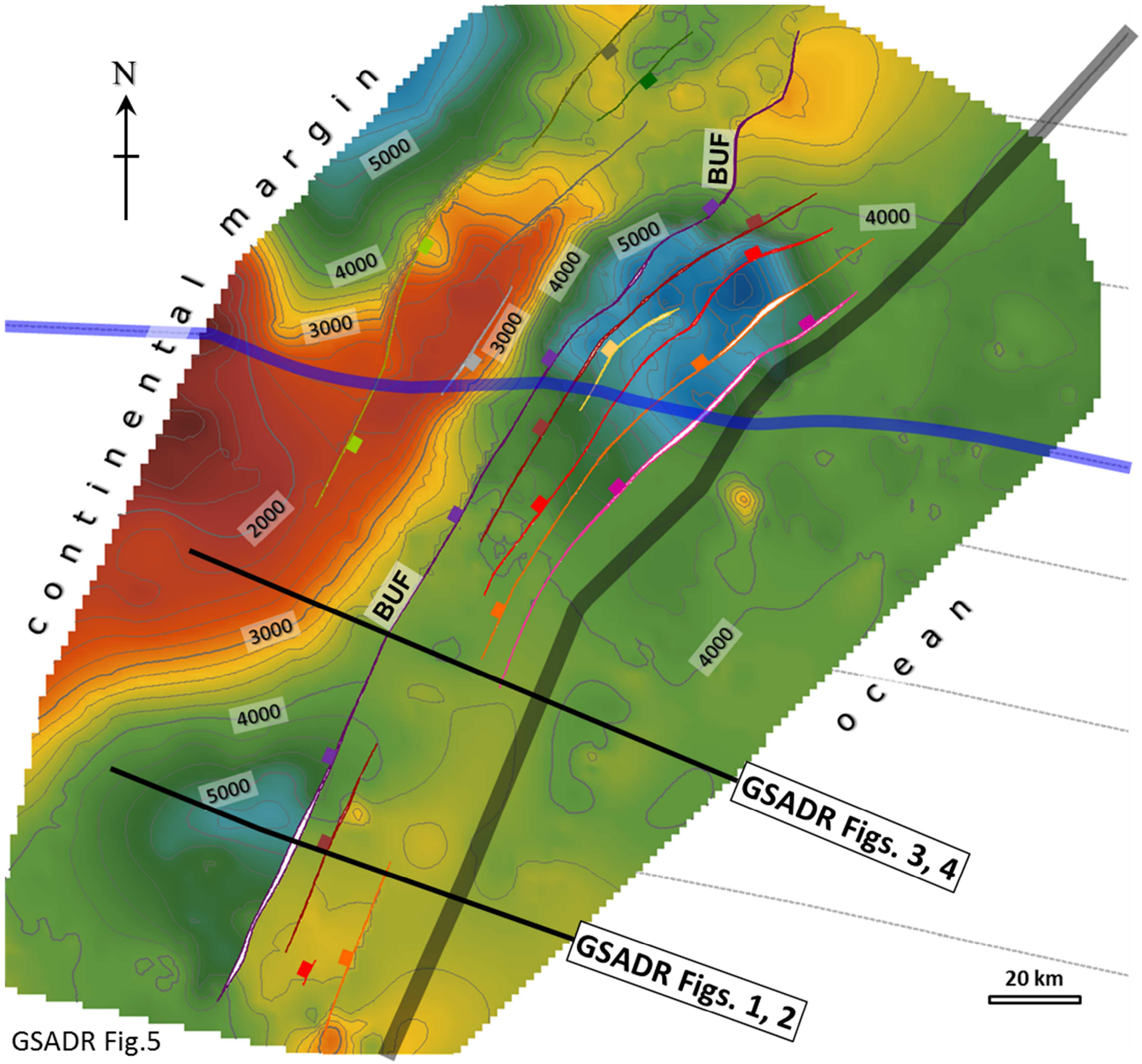
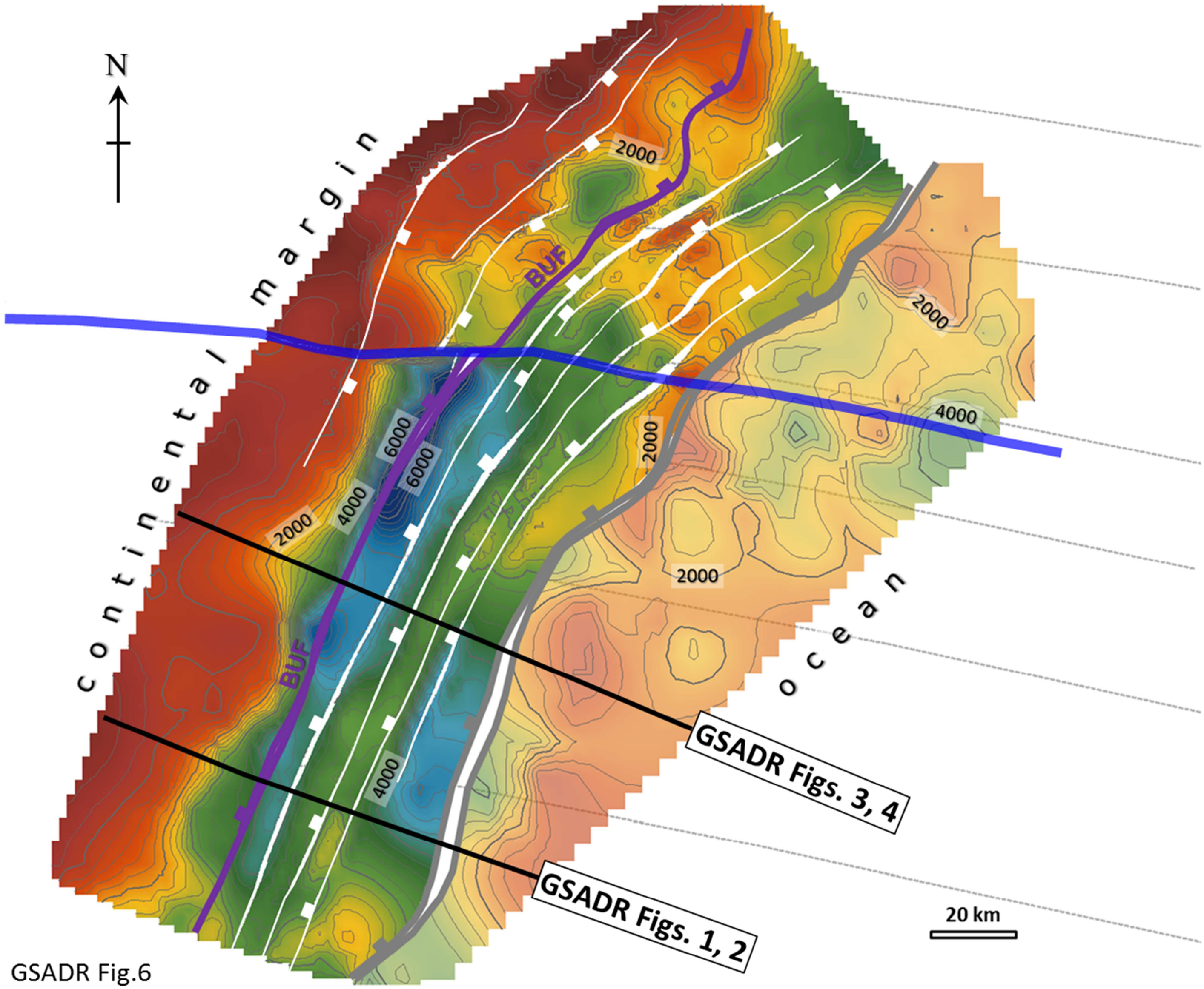
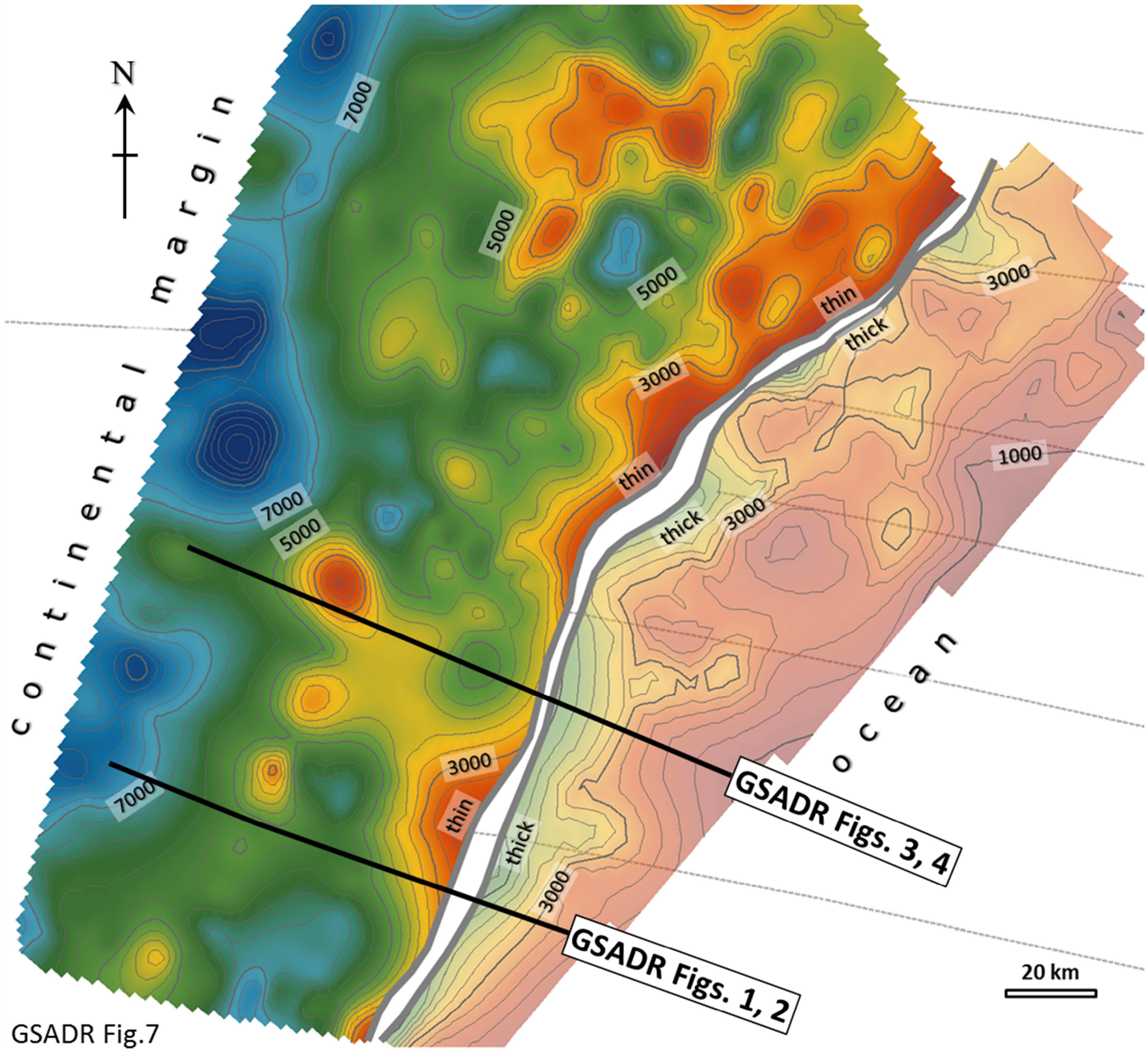

N
continental margin
ocean
BUF
BUF
5000
4000
3000
2000
3000
4000
5000
5000
4000
3000
4000
4000
GSADR Figs. 3, 4
GSADR Figs. 1, 2
20 km
GSADR Fig.5

Figure DR5. Depth to top of SDRs (red shading - shallow; blue shading - deep) between continental margin and OCB (thick grey line) plus depth of top of igneous oceanic crust (east of OCB). Contour values shown are in metres below mean sea-level. Normal faults are also shown. BUF - break-up fault. Thick blue line indicates major fracture zone and dashed grey lines the position of other oceanic fracture zones at the top of igneous oceanic crust.


N
continental margin
ocean
BUF
BUF
2000
2000
2000
2000
2000
4000
4000
4000
6000
6000
GSADR Figs. 3, 4
GSADR Figs. 1, 2
20 km

GSADR Fig.6

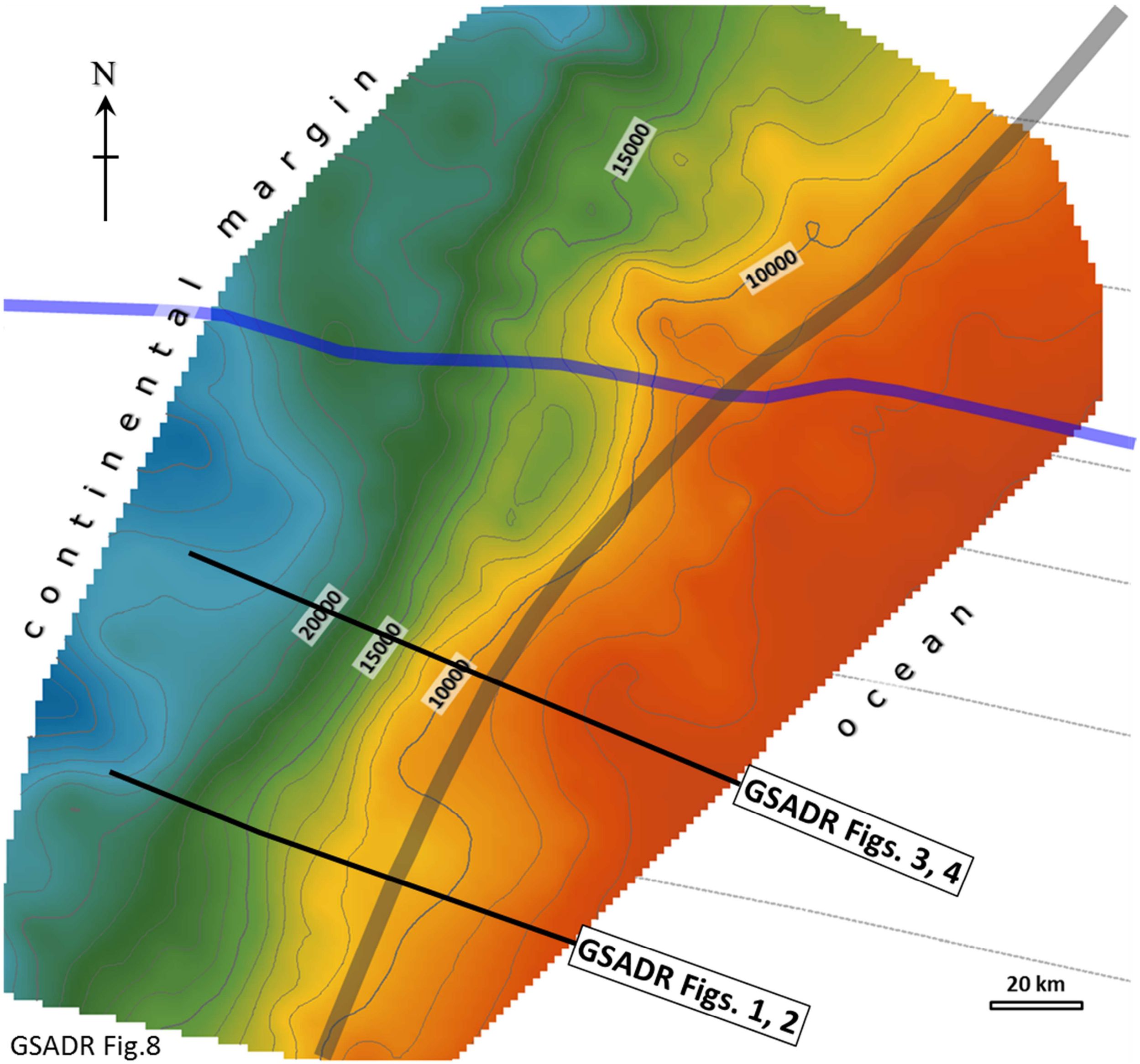
Figure DR6. Thickness map of SDRs (red shading - thin; blue shading - thick) between continental margin and OCB (thick grey line) plus thickness of upper layer of igneous oceanic crust (semi-transparent shading east of OCB, assumed to be pillow lavas and dolerite dykes). Contour values shown are in metres. Normal faults at base of SDRs are also shown (tick indicating direction of down-throw). BUF - break-up fault. Thick blue line - major fracture zone. Thin dashed grey lines - position of other oceanic fracture zones at top of igneous oceanic crust.



N
continental margin
ocean
7000
5000
3000
1000
thin
thick
GSADR Figs. 3, 4
GSADR Figs. 1, 2
20 km

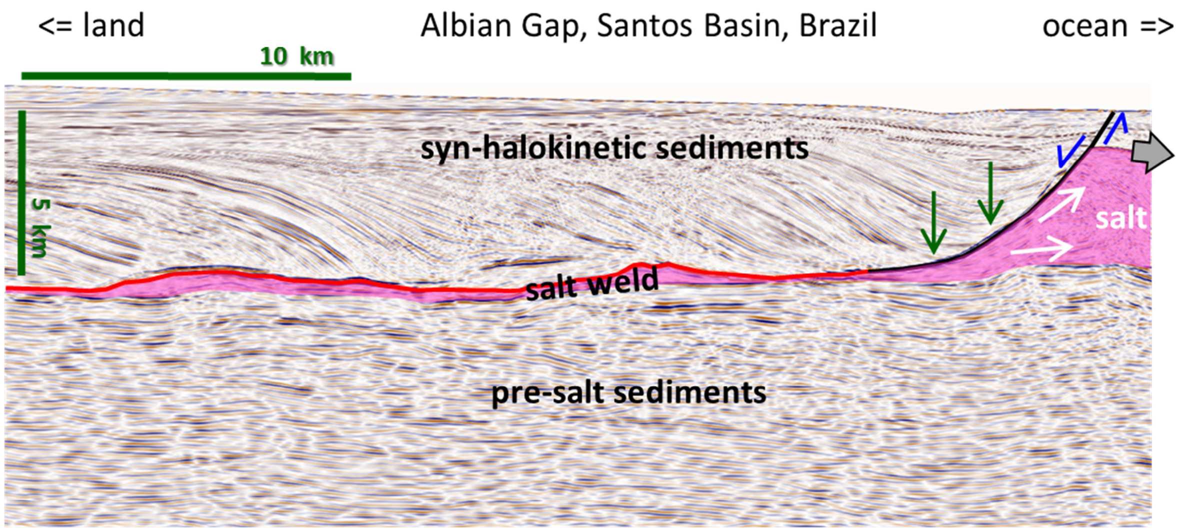
GSADR Fig.7

Figure DR7. Thickness map of lower crust, including MTZ. Blue shading - thick; red shading – thin. Contour values shown are in metres. Between the continental margin and OCB (thick grey line) the interval comprises transitional crust mobile layer and east of OCB it comprises lower oceanic crust (semi-transparent), interpreted in both regions to consist of ultramafic and mafic rocks. Dashed grey lines indicate the position of oceanic fracture zones at the top of igneous oceanic crust.

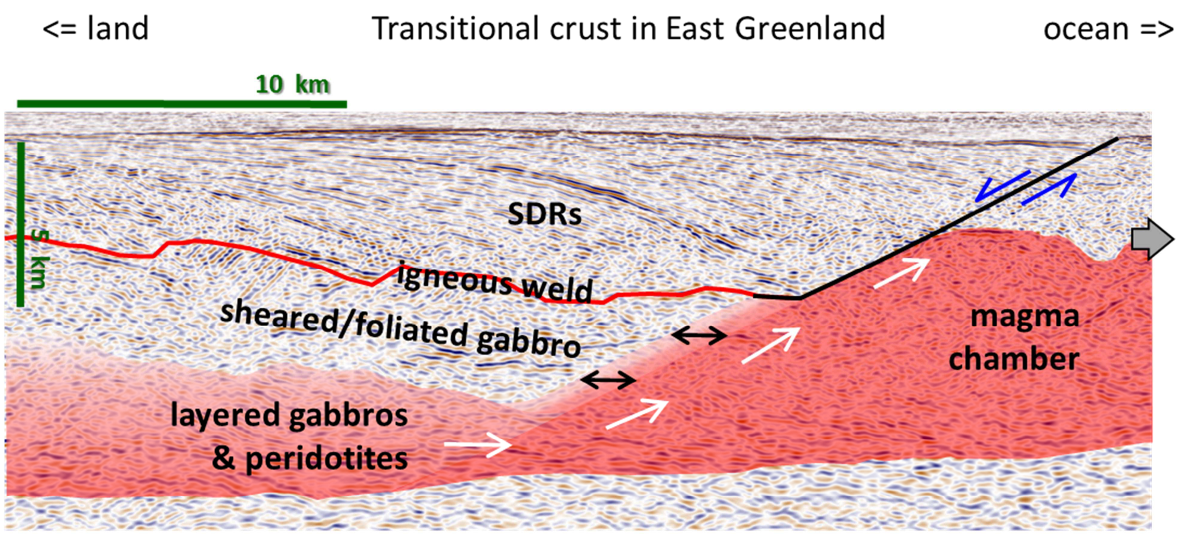

N
continental margin
ocean
15000
10000
20000
15000
10000
GSADR Figs. 3, 4
GSADR Figs. 1, 2
20 km

GSADR Fig.8

Figure DR8. Thickness map of entire igneous crust (blue shading - thick; red shading - thin). Between the continental margin and OCB (thick grey line) the interval comprises transitional crust, including SDRs and east of OCB it comprises oceanic crust. Contour values shown are in metres. Thick blue line indicates major fracture zone and dashed grey lines the position of other oceanic fracture zones at the top of igneous oceanic crust.



<= land
Albian Gap, Santos Basin, Brazil
ocean =>
10 km
5 km
syn-halokinetic sediments
salt
salt weld
pre-salt sediments



<= land
Transitional crust in East Greenland
ocean =>
10 km
5 km
SDRs
igneous weld
sheared/foliated gabbro
magma chamber
layered gabbros & peridotites

GSADR Fig.9

Figure DR9. Comparison of syn-halokinetic strata and SDRs, both of which developed during flow of viscous fluid (white arrows) in association with normal fault movement (blue arrows). These pre-stack depth migrated seismic sections are at the same 1:1 horizontal-vertical scale. Black line – normal fault. Red line - weld. The upper section shows sediments deposited during oceanward evacuation of salt (pink shading), which flowed down-dip, carrying the footwall with it (grey arrow), leaving behind a salt weld onto which the hangingwall settled (green arrows) (Quirk et al., 2012). The image is courtesy of the WesternGeco/TGS Brazil Data Alliance. The lower section is an illustration of the SDR model described in the accompanying paper where the footwall moves away from the hangingwall driven plate separation (grey arrow), gabbro is accreted in a ductile extension-accretion zone (black arrows) and basalt lava flows (SDRs) grow and weld onto a flat igneous contact, marking the top of the gabbro.

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