Title: Integrated 3D structural, thermal, gravity and rheological modeling of the Alps and their forelands – INTEGRATE

PIs: Magdalena Scheck-Wenderoth (RWTH Aachen University / GFZ-Potsdam), Judith Bott (GFZ-Potsdam), Jörg Ebbing (Christian Albrechts University Kiel), Hans-Jürgen Götze (Christian Albrechts University Kiel)
Postdoc: Josef Sebara (Christian Albrechts University Kiel)
PhD: Cameron Spooner (University of Potsdam / GFZ-Potsdam)

The aim of the project is to obtain a better understanding of the crust and the uppermost mantle beneath the Alpine orogen and its forelands using multiple 3D modelling techniques, such as gravity and thermal modelling, to test different hypotheses on the configuration of the lithosphere and its relation to the distribution of deformation and seismicity in the region. An additional objective of this project is to compile a homogeneous gravity dataset across the entire Alpine area and to create related gravity products so that they can be used both within the modeling of this project but also for additional studies from small to regional to continental scales, to encourage further research and discussion in the region. Progress on these deliverables is significant with an estimated release during 2021.

As a first step in interrogating the relationship between seismicity localisation and lithospheric structure, a seismically constrained, 3D, structural and density model of the lithosphere of the Alps and their respective forelands, derived from integrating numerous geoscientific datasets, was created. The generated model was adjusted to match the observed gravity field in the region. The findings suggest that the present-day Adriatic crust is both thinner (on average ~22.5 km) and denser (2800 kg/m^3) than the European crust (~27.5 km, 2750 kg/m^3). Crust derived from different terranes was also found to have significantly different densities with Alpine zones of Adriatic provenance such as the Austro-Alpine and Southern Alps, found to be denser and those of European provenance such as the Helvetic Zone and Tauern Window to be less dense, indicating the respective plates prior to orogenesis may be assumed to have had similar differences in crustal properties to the present day. In addition we found that the distribution of seismicity and deformation within the region correlates strongly to crustal features of the generated model, with vertical displacement rates shown to correspond to crustal thicknesses (Fig. 1a) and seismicity correlating with density contrasts within the crust.

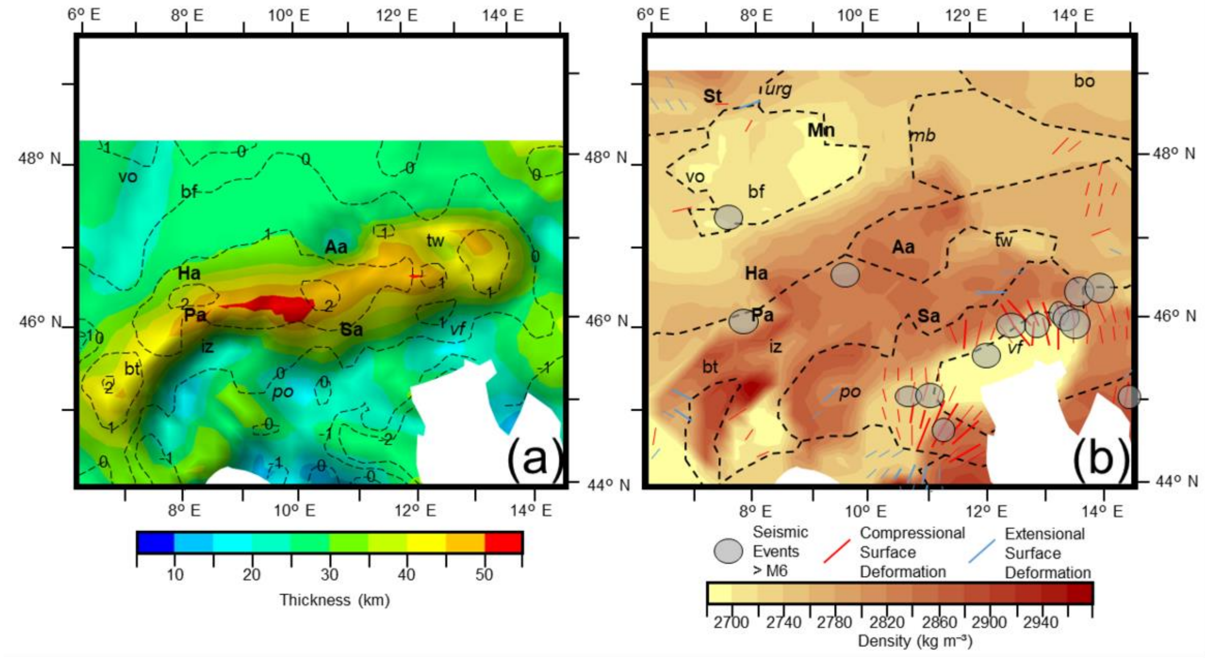

Figure 1. a) Thickness of the crust across the modelled area overlain with vertical displacement rates (Sternai et al., 2019). Dotted black lines indicate isolines relating to the vertical displacement rates in mm/a. b) Average density of the crust across the modelled area overlain with geodetically derived horizontal surface

strain distribution from (Sánchez et al., 2018) and seismic events of a Moment Magnitude over magnitude 6 (Fäh et al., 2011; Stucchi et al., 2012; Grünthal et al., 2013). Stick orientation indicates orientation of maximum surface strain. Dotted black lines indicate the upper crust density domains of the final structural and density model produced in this work. Frames of (a) and (b) represent the extent of the 3D model, while regions where the overlain data was not available have been whited out. Locations of key tectonic features are also overlain: St – Saxothuringian; Mn – Moldanubian; Aa – Austro-Alpine Zone; Ha – Helvetic Alps; Pa – Penninic Alps; Sa – Southern Alps; bo – Bohemian Massif; vo – Vosges Massif; bf – Black Forest Massif; tw – Tauern Window; bt – Briançonnais Terrane; iz – Ivrea Zone; urg – Upper Rhine Graben; mb – Molasse Basin; po – Po Basin.

To further interrogate the causes of seismicity localization, the steady-state conductive lithospheric temperature field was calculated based on assumptions on the composition of the crust and mantle derived from the density model and seismic velocities. The model is validated with a dataset of wellbore temperatures from across the region. The findings suggest that the Adriatic crust is more mafic, through its radiogenic heat production values (1.30E-06 W/m3) and maximum temperature of seismicity (600 °C), than the European crust (1.3-2.6E-06 W/m3 and 450 °C). It is also shown that at depths of <10 km the thermal field is largely controlled by sedimentary blanketing or topographic effects, whilst the deeper temperature field is primarily controlled by the LAB topology (lower thermal boundary condition) and the distribution and parameterization of radiogenic heat sources within the upper crust.

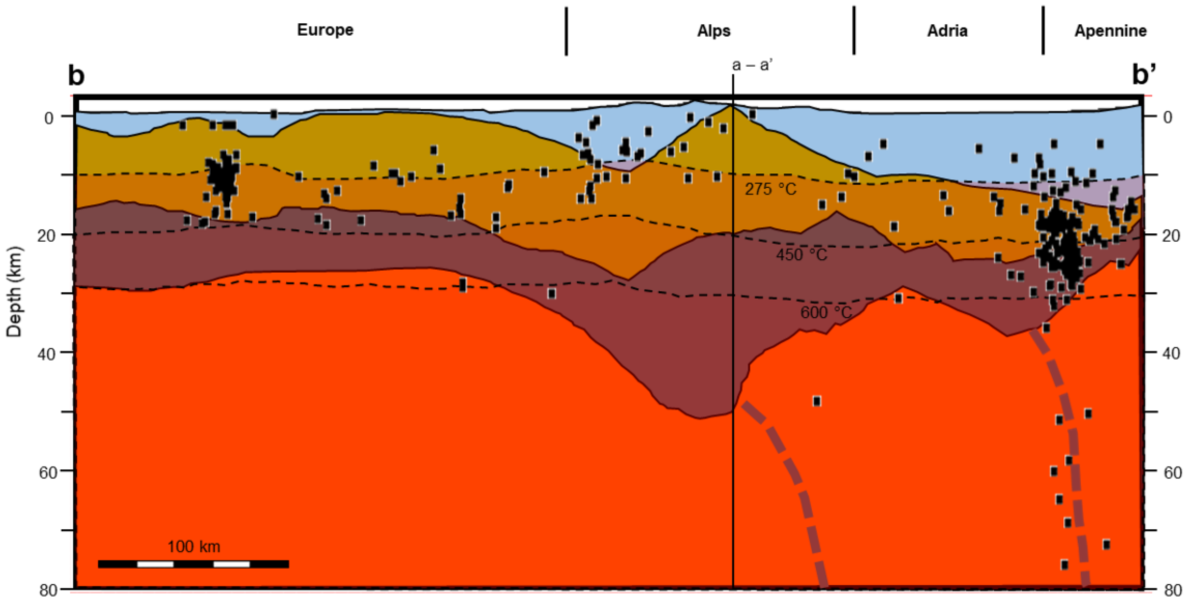

Figure 2. North to South cross section through the structural model, showing the isotherms for 275°C, 450°C and 600°C and seismicity (hypocentres as black squares) from the International Seismological Centre (International Seismological centre, 2020) that lay within 20 km distance of the section. Lithospheric mantle (red), lower crust (grey), upper crust (brown) and consolidated and unconsolidated sediments (blue). The location of known subduction interfaces have been marked as thick grey dashed lines.

Work utilising the 3D density and thermal models to calculate 3D variations of the long term lithospheric strength is ongoing, in order to discuss how composition and temperature impact the location of seismicity and other deformation indicators.

The project contributes to Themes 3: 'deformation of the crust and mantle during mountain building', and 4: 'motion patterns and seismicity', of the call for proposals. For Theme 3, the project has already provided the density configuration of the different crustal units and of the lithospheric mantle and for Theme 4, the project has identified spatial relationships between seismicity in relation to the crustal configuration. Due to its regional and data-integrative character, the project links with the different activity fields of the SPP and benefits from a continuous exchange of observations and modelling results with many working groups in the SPP.

Publication list

Journal:

- Spooner, C., Scheck-Wenderoth, M., Götze, H., Ebbing, J. and Hetényi, G., 2019. Density distribution across the Alpine lithosphere constrained by 3D gravity modelling and relation to seismicity and deformation. Solid Earth, 10(6), pp.2073-2088, https://doi.org/10.5194/se-10-2073-2019.
- Spooner, C., Scheck-Wenderoth, M., Cacace, M., Götze, H. and Luijendijk, E., 2020. The 3D thermal field across the Alpine orogen and its forelands and the relation to seismicity. Global and Planetary Change, 193, p.103288, https://doi.org/10.1016/j.gloplacha.2020.103288.

-Lowe, M., Ebbing, J., El-Sharkawy, A., and Meier, T.: Gravity Effect of Alpine Slab Segments Based on Geophysical and Petrological Modelling, Solid Earth Discuss., https://doi.org/10.5194/se-2020-145, in review, 2020.

Data Publications:

- Spooner, C., Scheck-Wenderoth, M., Götze, H., Ebbing, J., Hetényi, G., 2019. 3D Gravity Constrained Model of Density Distribution Across the Alpine Lithosphere. GFZ Data Services, https://doi.org/10.5880/GFZ.4.5.2019.004.

Conference:

- Götze, H., Bielik, M., Bott, J., Bonvalot, S., Braitenberg, C., Ebbing, J., Gabriel, G., Gosar, A., Hetényi, G., Kissling, E., Meurers, B., Mrlina, J., Novak, P., Papco, J., Pasteka, R., Sebera, J., Szűcs, E., and Zahorec, P., 2019. *A new land-based gravity data set for the Alps and adjacent regions – the AAGRG at work.* EGU General Assembly, 11 April 2019, Vienna.
- Götze, H., and the AlpArray Gravity Research Group, 2020. Completed in Spring 2020: AAGRG´s new recompilation of the Alpine gravity field, EGU General Assembly, 7 May 2020, Online.
- Scheck-Wenderoth, M., Spooner, C., Bott, J. Götze, H., Ebbing, J., 2019. *Present-day lithosphere configuration of the Alps and their forelands.* Invited talk at International workshop "The Geology of Eurasia", 27 June 2019, Potsdam.
- Scheck-Wenderoth, M., Bott, J., Cacace, M., Anikiev, D., Gomez Dacal, M. L., Spooner, C., and Gholamrezaie, E., 2020. *Thermal signature of the lithosphere below sedimentary basins in extensional, compressive and transform settings*. EGU General Assembly, 5 May 2020, Online.
- Scheck-Wenderoth, M., Spooner, C., Bott, J. Götze, H., Ebbing, J., Sebera, J. 2019. *Lithosphere structure of the Alps and their foreland.* IUGG General Assembly, 13 July 2019, Montreal.
- Sebera, J., Papčo, J., Götze, H., Pašteka, R., Zahorec, P., Bielik, M., Ebbing, J., Meurers, B., Mrlina, J., Bonvalot, S., Seoane, L., Gabriel, G., Skiba, P., Szűcs, E., Braitenberg, C., Gosar, A., Hetényi, G., and the AlpArray Gravity Research Group (AAGRG)., 2019. *A first Alps-dedicated gravity data set – introduction and status of the AlpArray gravity field activities.* EGU General Assembly, 12 April 2019, Vienna.
- Spooner, C., Scheck-Wenderoth, M., Bott, J., Götze, H., Ebbing, J., Sebera, J and Hetényi, G., 2019. *Mass distribution and thermal field across the Alpine orogen and its forelands.* EGU General Assembly, 11 April 2019, Vienna.
- Spooner, C., Scheck-Wenderoth, M., Cacace, M., Götze, H and Luijendijk, E., 2020. *The thermal field across the Alpine orogen and its forelands and the relation to seismicity.* EGU General Assembly, 7 May 2020, Online.