SPP 2017 Project: Stress transfer and Quaternary faulting in the northern Alpine foreland
(short: StressTransfer)

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Work Report – Status Feb. 2020

Abbreviations

ASZ	Albstadt Shear Zone
ERT	Electrical Resistivity Tomography
GPI	Geophysical Institute
GPR	Ground Penetrating Radar
KIT	Karlsruhe Institute of Technology
LED	Landeserdbebendienst (LED), Seismological Service of the state of Baden-Württemberg
LiDAR	Light Detection and Ranging
MB	Molasse Basin
RGBF	Rhine Graben Boundary Fault
URG	Upper Rhine Graben

Personnel

The hiring of a PhD for StressTransfer was much more complicated than anticipated. Two highly qualified candidates from KIT-GPI preferred to change to the industry on short notice. After a job advertisement, 12 applications and a lot of bureaucracy, M.Sc. Sarah Mader was hired who changed from University of Hamburg to Karlsruhe (incl. another 3 months delay for the period of notice). Finally, Mrs. Mader started on 1st March 2018 at the KIT-GPI in Karlsruhe. She quickly got familiar with the tasks in StressTransfer, learnt to install and service the field instruments, implemented the analysis software and coded new analysis scripts in Python / ObsPy. She also attended for example the 4D-MB Alpine Field Trip (7. - 12. September 2018), http://www.spp-mountainbuilding.de/short-course/field_trip_2018/index.html and several science meetings. Due to the initial delays there is a time shift of about one year in the work program relative to the first proposal, but this does not lead to changes in the work program as regards content.

Fieldwork

The seismological field work was very extensive and included two operations: (a) running of 10 seismic broadband stations for UNIBRA / AlpArray seismic network (Hetényi et al., 2018), (b): search for, installation of, and running of 15 recording stations for StressTransfer to locally densify AlpArray seismic network (Fig. 1).

(a): KIT-GPI provided 9 KABBA mobile stations and the permanent station BFO for the UNIBRA / AlpArray seismic network (stations A120A-A129A, see Table 1). These stations recorded for AlpArray before DSEBRA was available. The Deutsches Seismologisches Breitband Array – DSEBRA, is a seismic instrument consisting of 100 portable seismic broadband recording stations which were acquired within 4D MB and which were used for AlpArray seismic network since spring 2018. Before spring / summer 2018 several German universities, including KIT, provided seismic recording stations in a joint effort called UNIBRA (University Broadband Array) to run the German part of the AlpArray seismic network. During the StressTransfer project we conducted three station service tours including the handing over of six station sites to DSEBRA in July 2018.

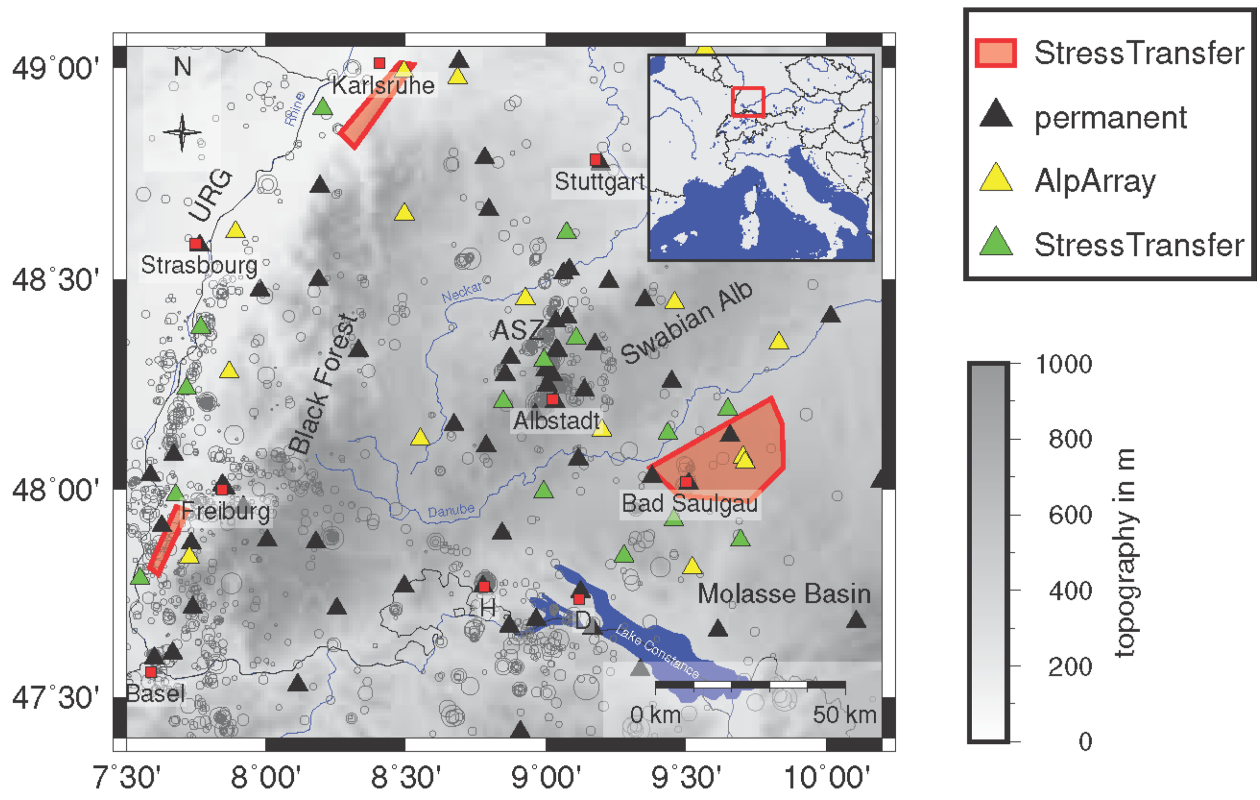

Fig. 1: Overview on study region. Seismological recording stations are indicated by triangles. Studied areas for neotectonics and paleoseismological trenches are shown in red. Historical and recent background seismicity are given as circles. Note our three main study regions: Upper Rhine Graben (URG), Albstadt Shear Zone (ASZ) and western Molasse Basin (MB) with StressTransfer stations in green. H: Hilzingen seismic swarm (2016-2017), D: Dettingen seismic swarm (2019).

AlpArray seismic network stations A126A, A127A, A129A, and BFO are still run by KIT-GPI. The data were/are preprocessed at KIT-GPI and transferred to the AlpArray data center.

(b): For StressTransfer we densified the AlpArray seismic network in the Upper Rhine Graben (URG), the Albstadt Shear Zone (ASZ), and the Molasse Basin (MB) with five recording stations each. First, we analyzed the existing networks (AlpArray and permanent LED network without strong motion stations) and selected possible location sites. Second, we searched for appropriate recording sites using GoogleMaps within a radius of about 3-4 km around the "perfect" site. Third, we conducted a field search, e.g. in August 2017, J. Ritter and K. Reicherter conducted a first station site finding tour in the MB and the ASZ regions. In spring 2018 S. Mader continued with the field work and contacted the responsible persons and associations (e.g. sport or rifle clubs with remote buildings), communities (e.g. with cemeteries or water reservoirs) or private persons. Fourth, finally M. Mader successfully installed all 15 stations (Fig. 1, Tab. 1). She was supported by KIT-GPI technicians and student helpers and together they executed also the following service tours. In July and August 2019 we used the DSEBRA gyrocompass to determine precisely the north direction of all 15 seismometers.

During the operation of the seismological StressTransfer network a major incident occurred: on 27th July 2019 an unexpected week number roll over of the GPS timing modules (Trimble Lassen SQ) took place and affected all our recorders (EarthData Loggers PR6-24). Since then a time shift of 1024 weeks affects the recordings (note: only the date is corrupt, not the synchronized time). Using software provided by GFZ Potsdam we can correct the data by a time shift of 1024 weeks beginning on the 17th August 2019. The data between the 27th July and 17th August is affected by a constant time shift of 388961152 seconds and can be also corrected. However, this procedure requires extra time for processing and checks of the data headers.

The tectono-morphological field- and lab work concentrated on two of our three envisaged areas (URG and MB). On basis of LiDAR image evaluation in high resolution (Fig. 2B), which we obtained from LGRB Freiburg, we selected several sites in the southern Upper Rhine Graben, as well as near Herbertingen/Danube in the Molasse Basin. Several students have achieved near-surface geophysics (e.g. Fig. 2C and Fig. 3), documented in their BSc or MSc theses. After extensive shallow geophysical and morphotectonic investigations and analyses (examples in Fig. 3), we discovered that the eastern central Rhine Graben Boundary Fault (RGBF) consists of several parallel fault strands that are marked by topographic steps, by varying hydrogeologic conditions (moisture content) and by geophysical anomalies in the subsurface (GPR and ERT data). Some of the scarps close to the alluvial plain of the river Rhine have been identified as erosional features (Fig. 2B).

LiDAR data help to identify characteristic fault-related landforms. The entire margin of the central Upper Rhine Graben is marked by triangular facets formed in the Buntsandstein, indicating rapid incision and shoulder-uplift (Fig. 2B). At some parts, uplift rates are larger than incision/erosion rates forming hanging valleys. In the so-called Vorbergzone south of Ettlingen a very prominent feature is the beheaded valley (BV in Fig. 2B), suggesting there is a considerable left-lateral strike-slip component on the RGBF. The genesis is unclear, and will be investigated in the second phase to determine long-term slip rates and displacements.

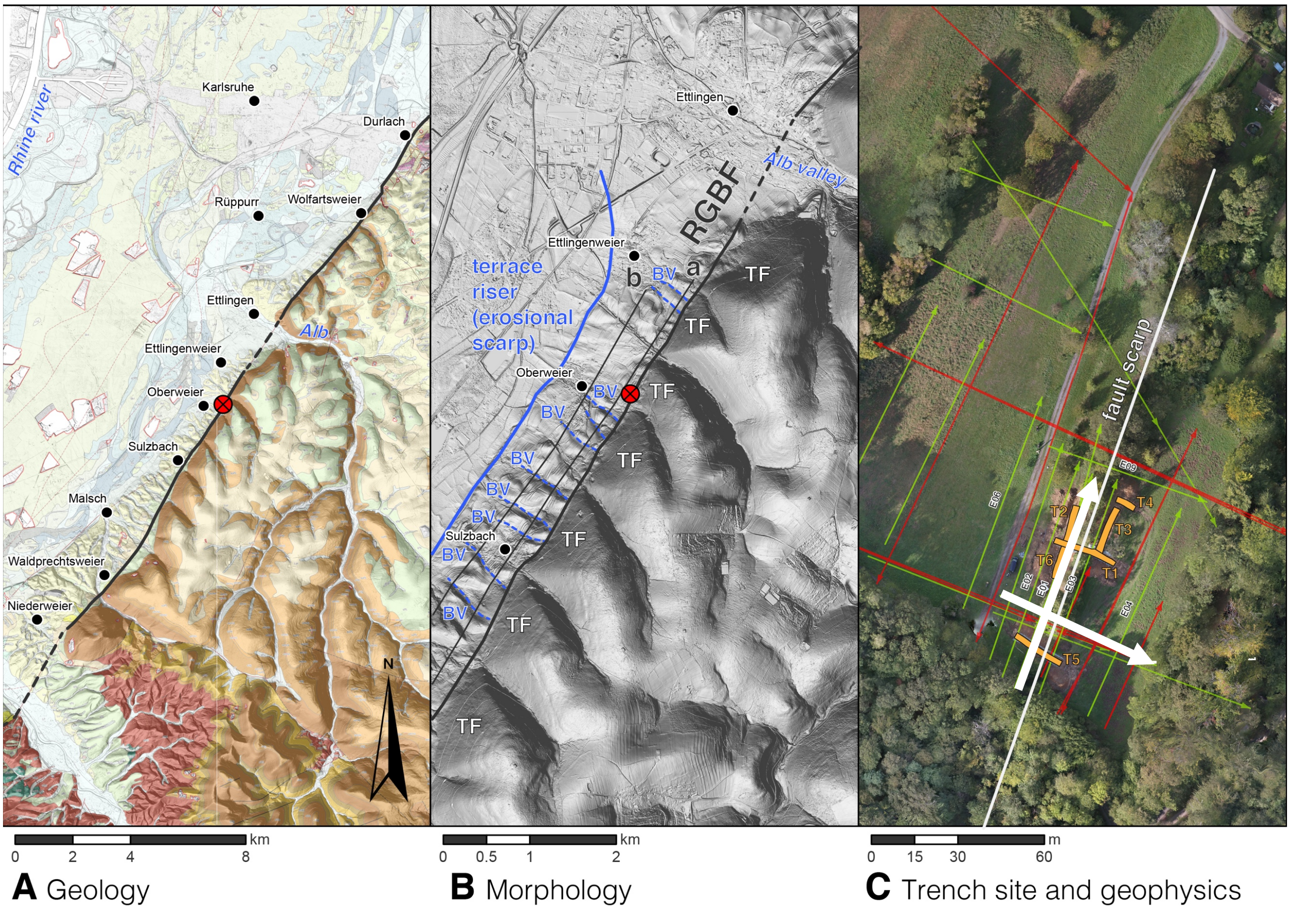

Fig. 2: A: Geological overview showing the area of the eastern Rhine Graben boundary fault zone (RGBF, thick black line) south of Karlsruhe (Fig. 1 for location). West of RGBF so-called Vorbergzone, east of RGBF Triassic basement (Buntsandstein). **B:** LiDAR-based topography of the Ettlingen area, note trench site near Oberweier (red circle). a: second order fault of RGBF (trench site), b: second order fault of RGBF, TF: triangular facet, BV: beheaded valley. Note that the youngest strand of the RGBF may be eroded by river Rhine (blue line). **C:** Detailed drone image of the trenching area near Oberweier with location of geophysical surveys. Green lines: ERT profiles (thick white arrows: ERT profiles see Fig. 3), red lines: GPR profiles, orange shapes: paleoseismological trenches (excavation September/October 2019), white line: fault scarp.

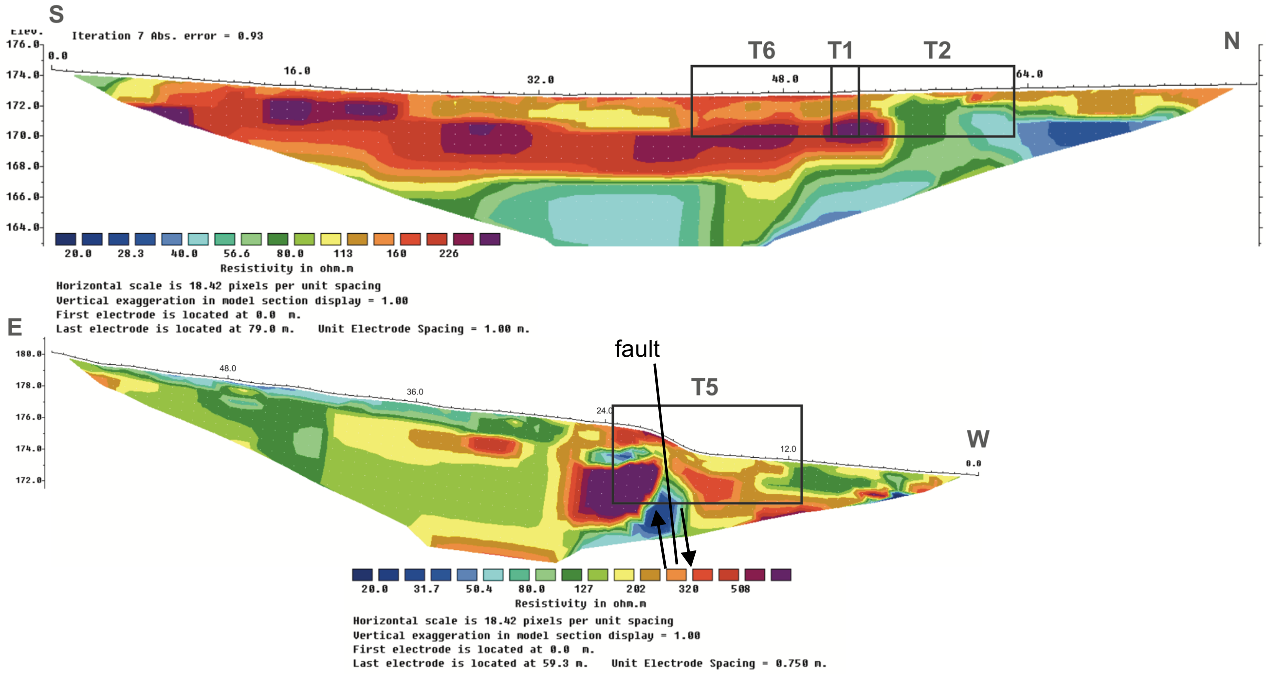

Fig. 3: Pre-trenching geophysical sections parallel (ERT profile E02, see Fig. 2C for location) and across the fault scarp (ERT profile E05, see Fig. 2C for location) at the trench site near Ettlingen-Oberweier. ERT sections (dipole-dipole array with electrode spacing of 1.00 and 0.75 m). Location of fault zone and trenches‘ extent (T1, T2, T5 and T6) marked. See Fig. 2C for location.

We opened six trenches perpendicular and parallel to the second topographic scarp (strand; a in Fig. 2B) of the main RGBF close to the town of Ettlingen (ca. 10 km south of Karlsruhe; Fig. 2). Trenching the main RGBF was precluded due to forest cover and the presence of big blocks of rock in the colluvium at the base of the slope (Buntsandstein, Bunter, red Triassic sandstones). Trenches were up to 20 m in length and 2 m in width, and up to 3 m in depth (Fig. 4). None of the trenches reached the Triassic Buntsandstein “basement”, and all exposed Pleistocene and Holocene strata. Some strata are interpreted as blocky/gravelly colluvium of the Glacial periods, Loess, redeposited gleyey Loess, soli-/gelifluction layers and deposits and organic paleosols. Most of these layers are clearly displaced by faults and downthrown to the west, although some strata appear to warp or fold over faults. Massive liquefaction and periglacial features have been found, the relation to the sedimentary sequences in the trenches need to be elaborated in future. The process is interpreted to be instantaneous, as massive colluvium is placed against clayey/silty loess deposits, and therefore we attribute these displacements to earthquake-related faulting. Creep along the strand can be ruled out. The displacement on free faces is on the order of 30 – 50 cm per event vertically (Fig. 4, right), and considerable horizontal offset (ca. 2 m), and we found evidence for tentatively two of such events by colluvial wedges. Applying the commonly used empirical relationships (Wells and Coppersmith, 1994), these findings are interpreted as two events with a magnitude *M* larger than 6.

Fig. 4: Paleoseismological trenching near Ettlingen-Oberweier in October 2019. Left: Overview, note vehicles for scale. Right: J. Hürtgen and K. Reicherter indicating a postglacial fault scarp with a vertical offset of approximately 30-35 cm.

Table 1: Seismological broadband stations which are part of the AlpArray network (Hetényi et al., 2018). Data are provided to the AlpArray database.

Code	Town nearby	Installation date	Replacement date by DSEBRA instrument
A121A	Sulzburg	25.07.2016	10.07.2018
A122A	Schmieheim	22.02.2016	10.07.2018
A123A	Kehl	26.02.2016	11.07.2018
A124A	Enzklösterle	23.02.2016	11.07.2018
A125A	Königsbach-Stein	18.04.2016	11.07.2018
A126A	Karlsruhe-Durlach	18.05.2014	still run by KIT-GPI
A127A	Annweiler Trifels	25.06.2012	still run by KIT-GPI
A128A	Plankstadt	27.10.2009	12.07.2018
A129A	Schmalenberg	29.02.2016	still run by KIT-GPI
BFO	Schiltach	before 2016	permanent KIT-GPI

Table 2: Recording stations for StressTransfer: AST0X: URG, AST1X: ASZ, AST2X: MB. See also Fig. 1.

Code	Town nearby	Installation date
AST01	Steinmauern, Rastatt	26.07.2018
AST02	Schwanau	05.07.2018
AST03	Niederhausen, Rheinhausen	10.07.2018
AST04	Rimsingen, Tuniberg	05.07.2018
AST05	Siedlung im Stein, Neuenburg a.R.	24.08.2018
AST11	Weil im Schönbuch	08.01.2019
AST12	Salmendingen	20.09.2018
AST13	Onstmettingen, Albstadt	30.10.2018
AST14	Hausen am Tann	19.09.2018
AST15	Worndorf	09.01.2019
AST21	Kümmerazhofen, Bad Waldsee	17.07.2018
AST22	Hattenweiler, Heiligenberg	18.07.2018
AST23	Hundersingen, Oberstadion	20.09.2018
AST24	Königseggwald	08.01.2019
AST25	Altheim, Langenenslingen	17.07.2018

Data Processing and Quality Check

To check the quality of the field recordings, which is mainly determined by the background noise and possible instrument problems, we calculate yearly power spectral density (PSD) diagrams of the ground motion for all StressTransfer stations (see Fig. 5). Our recordings have well acceptable noise levels and fulfill our requirements to observe micro-seismic events with a mobile network. The highest noise level is observed in the URG (Fig. 5a) – here all StressTransfer stations are installed on thick Quaternary and Tertiary sediments and there is enormous anthropogenic noise (traffic, industry & residential areas). However, these stations allow an improved event location compared to observations only on the rift shoulder (nearly all LED stations are placed on the shoulders of the URG on solid rock with low noise conditions). The noise level around the AZS (Fig. 5b) is clearly lower compared to the URG, especially in the high frequency band (here >1 Hz). Around the ASZ most stations are deployed on relatively solid Mesozoic limestone. The noise level in the Molasse basin (Fig. 5c), where there are Quaternary sediments, is between the one in the URG and the one around the ASZ. As there are few permanent recording stations, our StressTransfer network together with the AlpArray seismic network provide a unique observational basis.

Most of our recording stations are equipped with Streckeisen STS2 seismometers (or STS2.5 at AST15)), except for the stations AST01 (KS2000) and AST13 (Güralp 40T). Therefore, there is a higher noise level in the low frequency range at the stations AST01 and AST03 (Fig. 5a), because the instruments are less sensitive in this range (this will not affect the recording of the local events which have high frequencies). At recording station AST24 (Fig. 5c) we had technical problems after installation, which is also visible in the PSD as a curved band. This problem has been fixed meanwhile.

Our EarthData Loggers PR6-24 use a linear phase FIR filter during the downsampling procedure to inhibit aliasing. As this type of filter is acausal, it can produce unwanted precursory signals, especially for impulsive signals. To remove this effect (which can sometimes be clearly visible), S. Mader coded and tested an ObsPy script based on the theory of Scherbaum (1996).

External Data Supply

We received the bulletin files of the Seismological Service of Baden-Württemberg (LED) for all earthquakes south of 49°N between 2011 and 2018 (2,274 earthquakes). The phase picking times are used for relocation of the events together with our own picks from recordings of the AlpArray and StressTransfer seismic networks.

Phase Picking

The phase picking is done with a self-coded ObsPy script which includes the picking criteria defined by Diehl et al. (2012). The uncertainties of the pick times are calculated automatically (but can be changed manually). The final pick time is chosen manually between the error boundaries. The quality of the pick time depends on the error boundaries to achieve a consistent data set. This quality assignment is done with similar uncertainties like the quality assignment of the picks of the LED, also for consistency. The polarity of a phase is determined for P- and SH-waves to allow for fault plane solution calculations. Up to now (Sept. 2019) we picked the recordings for the Albstadt Fault Zone events from 2016 to 2018. This leads to 1,108 additional P-and S-phase picks from 4 AlpArray and 3 StressTransfer seismic stations. These data were already used for modelling, see below. Furthermore, we started picking the P- and S-phases of earthquakes in the Upper Rhine Graben (URG) from nine AlpArray seismic stations. For the URG we complemented the LED earthquake catalogue with 2245 additional P-and S-phase picks for the years 2016, 2017 and 2018 (still ongoing work). For the year 2018 we also started picking the seismic waveforms on our five StressTransfer seismic stations.

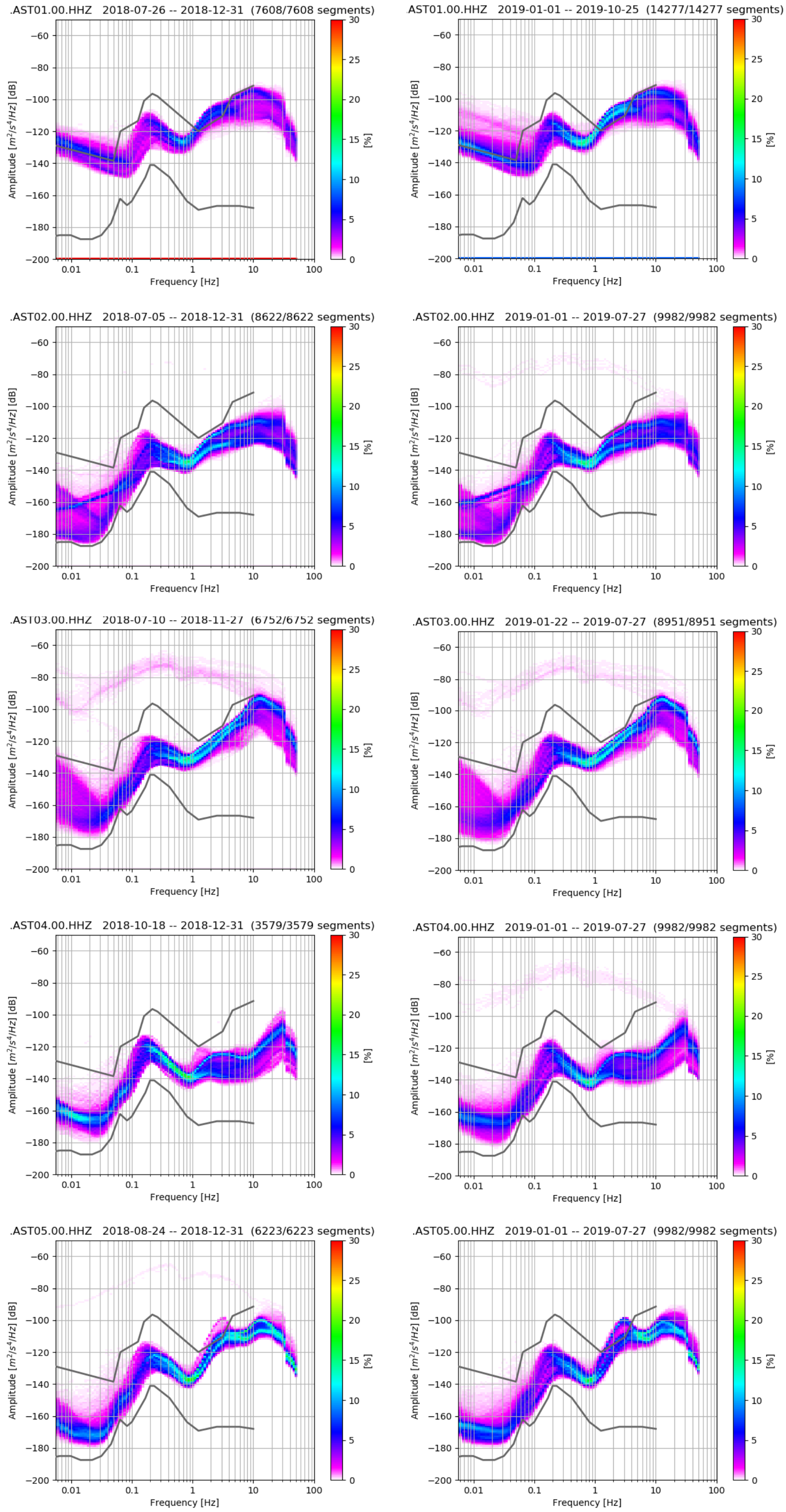

Fig. 5a: Power Spectral Density (PSD) of the StressTransfer recording stations in the Upper Rhine Graben (AST01-AST05, see Table 2). Left: recordings in 2018, right: recordings in 2019. The two grey solid lines indicate the New High Noise Model and New Low Noise Model of Peterson (1993). Colour indicates relative number of occurrences in one-hour long time windows. Splitting in the high frequency range indicates differences between day time (high) and night time (low) noise conditions.

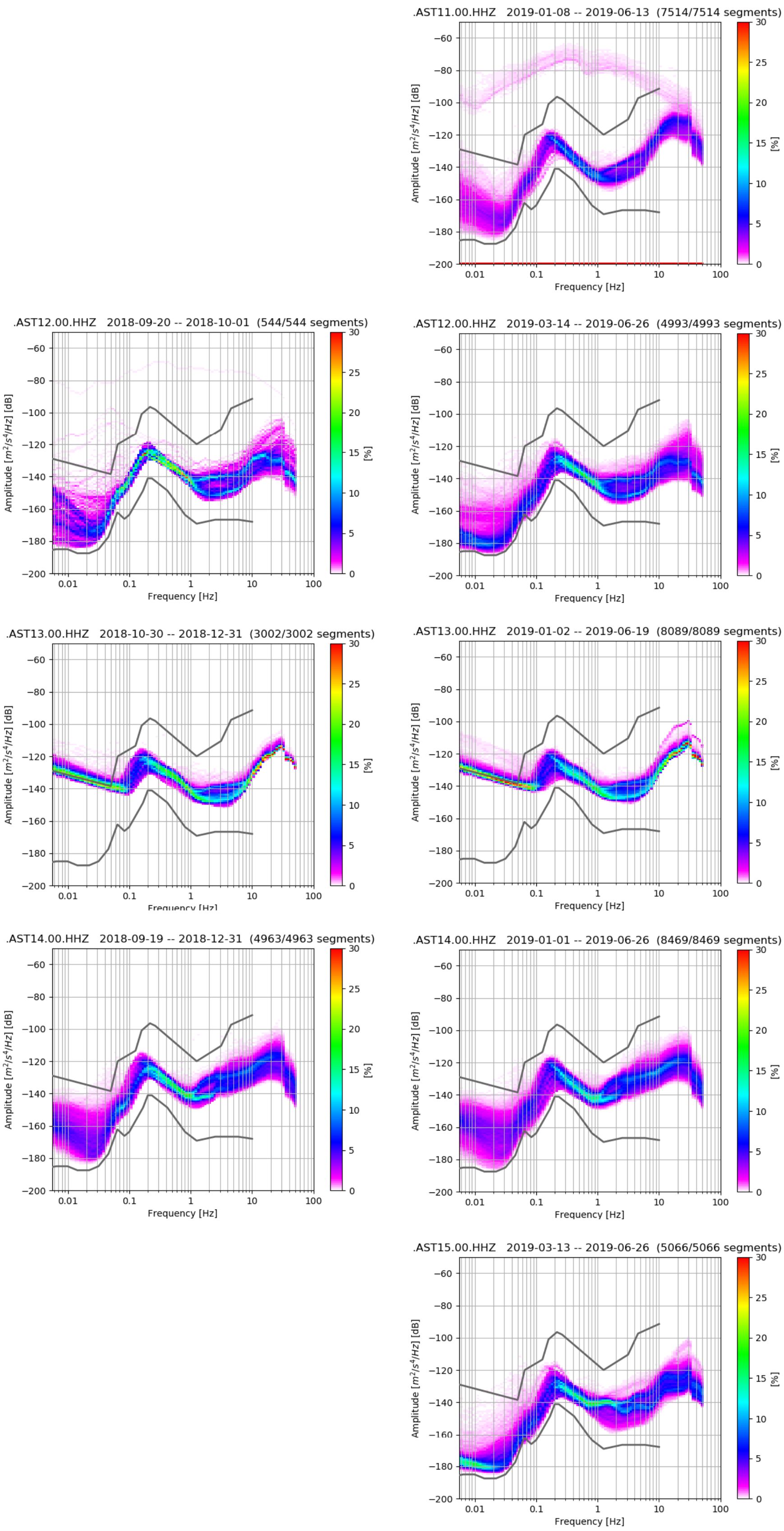

Fig. 5b: Power Spectral Density (PSD) of the StressTransfer recording stations around the Albstadt Shear Zone (AST11-AST15, see Table 2). Left: recordings in 2018, right: recordings in 2019. The two grey solid lines indicate the New High Noise Model and New Low Noise Model of Peterson (1993). Colour indicates relative number of occurrences in one-hour long time windows. Splitting in the high frequency range indicates differences between day time (high) and night time (low) noise conditions.

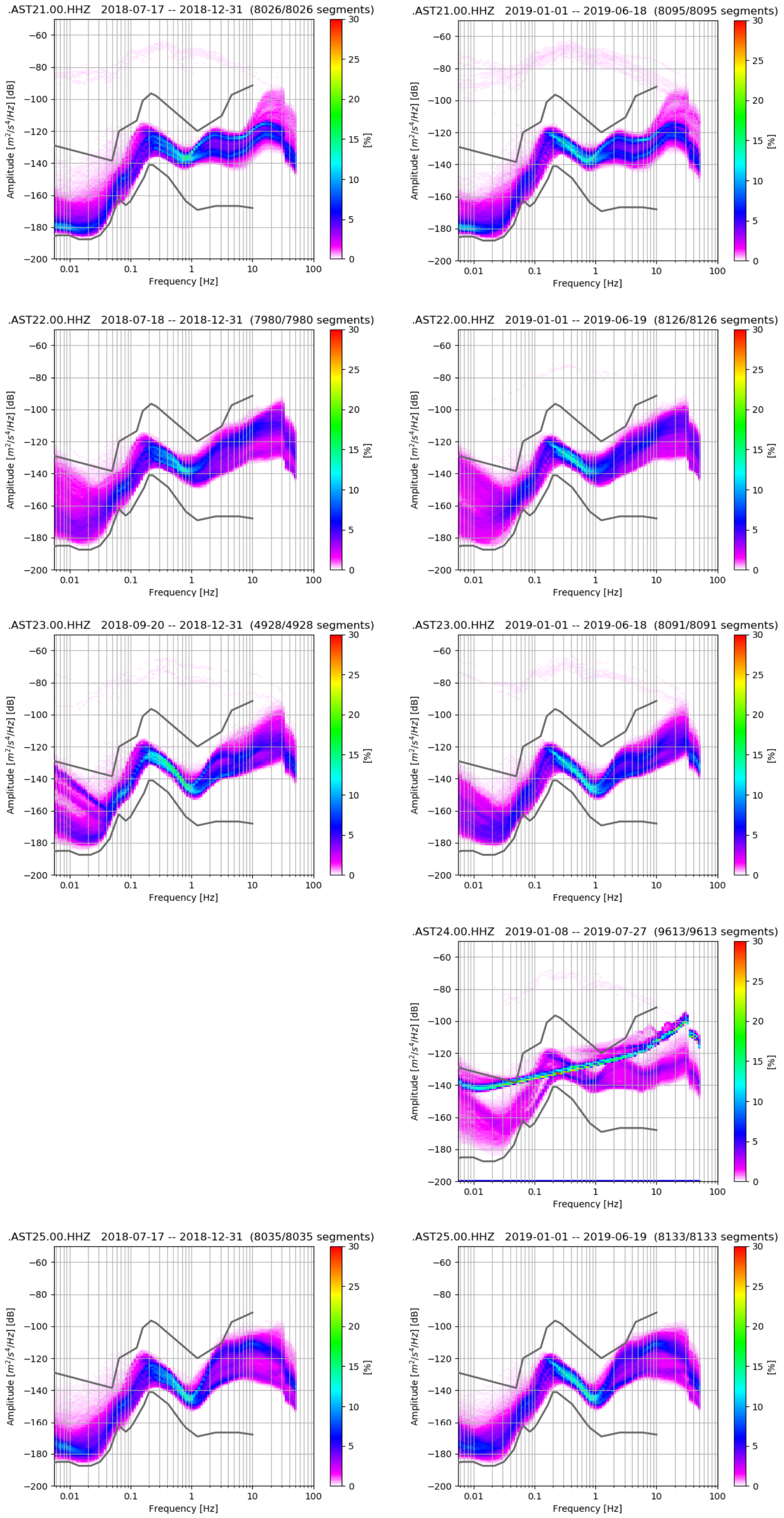

Fig. 5c: Power Spectral Density (PSD) of the StressTransfer recording stations in the Molasse Basin (AST21-AST25, see Table 2). Left: recordings in 2018, right: recordings in 2019. The two grey solid lines indicate the New High Noise Model and New Low Noise Model of Peterson (1993). Colour indicates relative number of occurrences in one-hour long time windows. Splitting in the high frequency range indicates differences between day time (high) and night time (low) noise conditions.

Modelling

A New Seismic Velocity Model for the Albstadt Shear Zone (ASZ)

For the Swabian Alb region around the ASZ we inverted for a new minimum 1D seismic velocity model using the VELEST algorithm (Kissling, 1995). As input we use an earthquake catalog with onset times and initial hypocenter parameters consisting of the 99 best-determined earthquakes in the area between 8.75°E - 9.15°E and 48.17°N - 48.5°N and with an observational gap (azimuth) of less than 150°. The phase catalog consists of 945 P- (pick quality 0 and 1) and 1019 S-phases (pick quality 0, 1 and 2). We used a staggered inversion scheme with first inverting for the compressional wave velocity (*vp*) and subsequently for both, *vp* and the shear wave velocity (*vs*). As input model we used four different layers from seismic refraction models and calculated for each layer setting 21 perturbed starting models to widely probe the model space. For the final seismic velocity model (Fig. 6) the simplest layering is chosen. It explains the data best in terms of a lowest root mean square difference (RMS) between input phase times and model-predicted phase times. Preliminary station corrections are determined for all stations to account for local site anomalies at the recording stations and 3-D heterogeneity between the target region (ASZ) and the partly remote recording sites. To test the velocity model we performed a stability test (Kissling, 1995) by shifting the hypocenters randomly in space and undamping the velocity model during the inversion. The result shows that stable hypocenter positions and stable seismic velocities are achieved except for the 2nd *vp* layer. This instability may be caused by less refracting rays through the 2nd layer and only few earthquake hypocenters within the 2nd layer (details will soon be submitted as manuscript to Solid Earth, SPP Special Volume).

Our new seismic velocity model in Fig. 6 is an improvement relative to earlier models: (a) compared to seismic refraction models (e.g. Gajewski et al., 1987) we have a better ray distribution, because sources at different depths are included and (b) compared to the LED model we determined a *vs* model separately (LED uses a fixed *vp*/*vs* ratio), and we determine station correction terms. The latter are very small in the direct vicinity of the ASZ, indicating that the local *vp* and *vs* depth models fit the "true" velocity at depth very well.

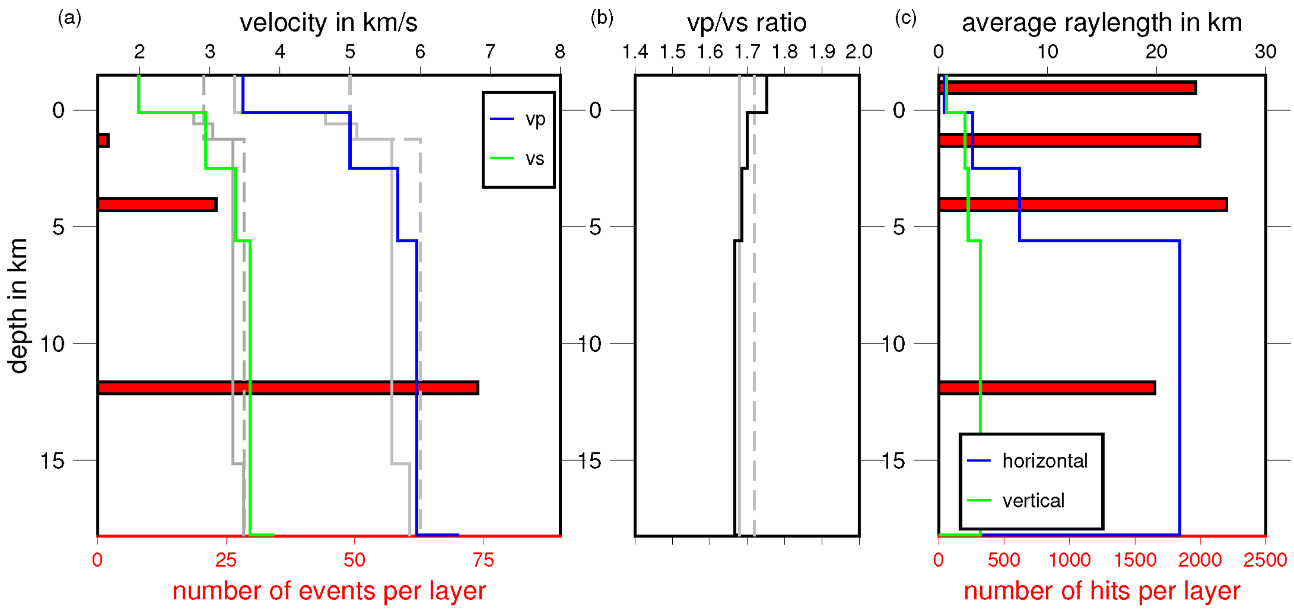

Fig. 6: Seismic velocity models (minimum 1-D using VELEST), *vp*/*vs* ratio and number of seismic rays per layer for the Albstadt Shear Zone region. In the second layer, the VELEST seismic velocity was slightly changed to obtain zero NonLinLoc station corrections in the center of the model. The grey dashed models are the LED Baden-Württemberg models, the grey solid models are the local Swabian Jura models of the LED.

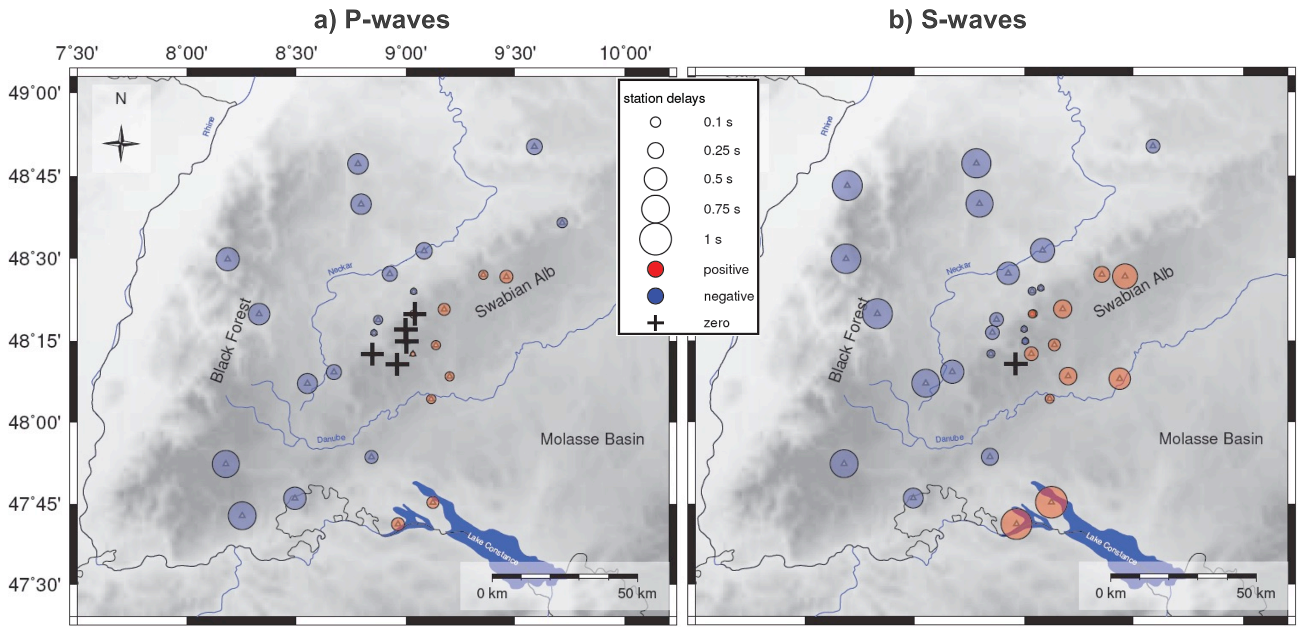

Fig. 7: Station correction terms for P-waves and S-waves using NonLinLoc. Note: (a) the very small terms in the center close to the ASZ, (b) the systematic changes with distance to the ASZ. These two properties indicate that the velocity models are well fitted to the ASZ.

Station Corrections, Hypocenters and Fault Plane Solutions

To relocated the earthquake catalogue of the years 2011-2018 for the area around the ASZ with 560 earthquakes, we use the program NonLinLoc by Lomax (2000) together with our new velocity models. NonLinLoc allows us to determine location uncertainties for each hypocenter with different algorithms and depending on picking uncertainties and velocity model uncertainties, furthermore, it also calculates station corrections (Fig. 7). To achieve zero NonLinLoc station correction in the center of the velocity model, we adjusted the seismic velocities in the second, unstable layer slightly.

Based on the final hypocenter uncertainties we select the best located earthquakes for interpretation of the ASZ (partly still work in progress). Preliminary it seems that the ASZ reaches as far as the Neckar river in the north (Fig. 8). Around the Zollern Graben, close to Hechingen, there seems to be a separate cluster of events. First fault plane solutions were determined with the program FOCMEC by Snoke (2003). In total 33 fault plane solutions were calculated for events from 2011 to 2018. For events with similar hypocenter and polarities a combined fault plane solution was calculated, to reduce the dependency on a few picks and the uncertainty of the fault plane solutions (in total 12 clusters were formed, only one single event solution is left). These solutions are displayed in Fig. 8 and indicate a mainly strike slip mechanism along the ASZ (as was known before). Interestingly, close to Hechingen at the Zollern Graben (a local NW-SE striking graben structure), the fault plane solutions seem to change (two normal faulting events). These first findings indicate that the seismicity of the ASZ is clustered on different segments.

Outlook

After the installation of the seismic stations the main seismological field work for StressTransfer is finished as proposed. In addition, the software for waveform analysis and inversion was also successfully implemented and tested. The first analysis, mainly focused on the ASZ, is very promising. The seismological results will surely be much more substantiated as soon as more data are incorporated (up to now only ca. 30% of the expected data is used for the models). As such the project is well within its proposed work program within the above mentioned time shift.

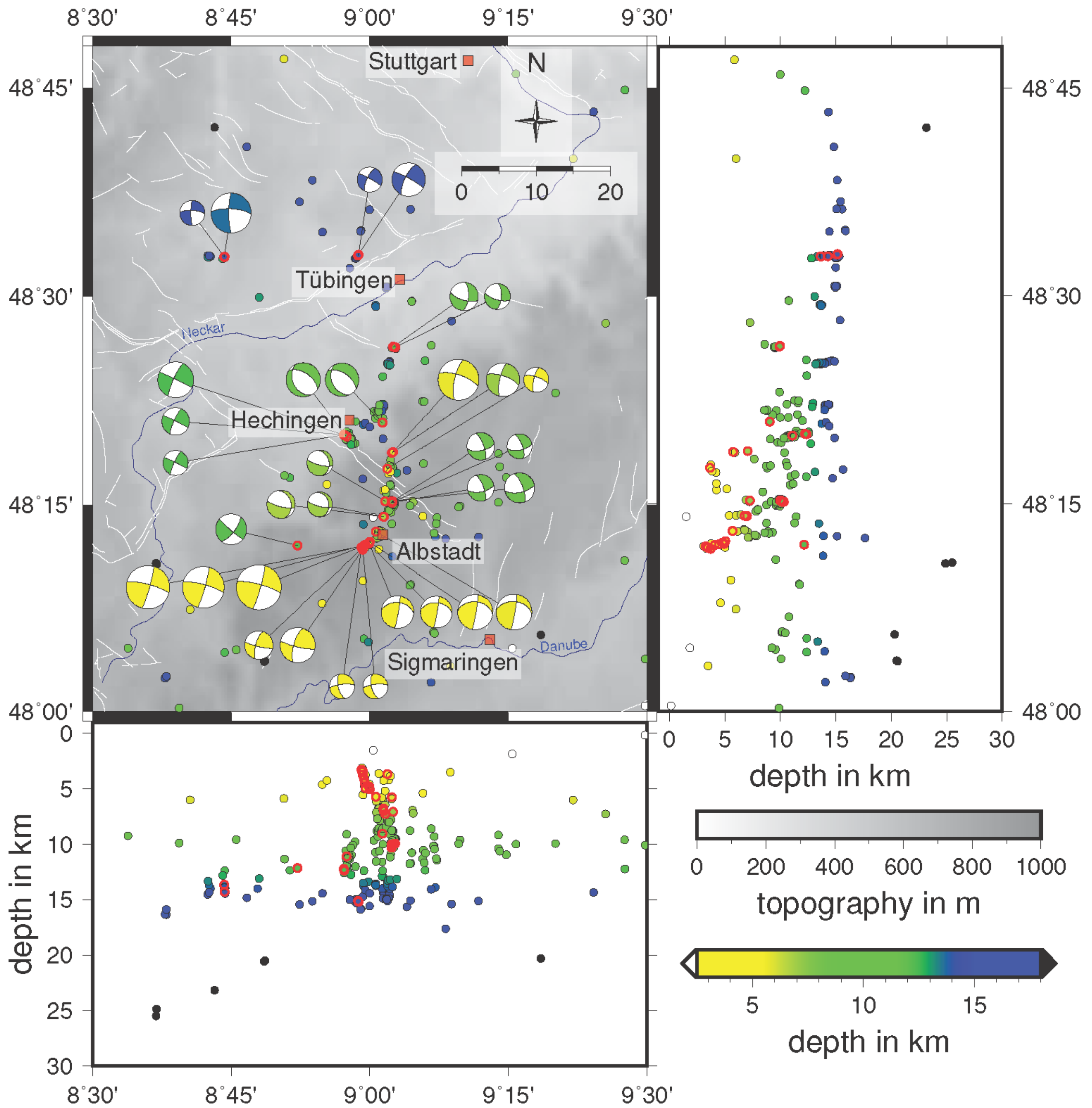

Fig. 8: Relocated earthquakes in and around the Albstadt Shear Zone, 2011-2018. There are also 33 selected fault plane solutions of events (red circles) with $1.0 \leq M_L \leq 3.5$, the size of the fault plane solutions is proportional to M_L.

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Publications, Science Meeting Contributions, Academic Thesis Work, Outreach

Peer-reviewed publication

Hetényi, G., Molinari, I., Clinton, J., Bokelmann, G., Bondár, I., Crawford, W.C., Dessa, J.-X., Doubre, C., Friederich, W., Fuchs, F., Giardini, C., Gráczer, Z., Handy, M.R., Herak, M., Jia, Y., Kissling, E., Kopp, H., Korn, M., Margheriti, L., Meier, T., Mucciarelli, M., Paul, A., Pesaresi, D., Piromallo, C., Plenefisch, T., Plomerová, J., **Ritter, J.**, Rümpker, G., Šipka, V., Spallarossa, D., Thomas, C., Tilmann, F., Wassermann, J., Weber, M., Wéber, Z., Wesztergom, V., Živčić, M., AlpArray Seismic Network Team, AlpArray OBS Cruise Crew and AlpArray Working Group, 2018. The AlpArray Seismic Network: a large-scale European experiment to image the Alpine orogen. Surv. Geophys., 39, 1009-1033.

Science Meeting Contributions

4D-MB SPP Meeting 2017, Potsdam: Overview on StressTransfer (K. Reicherter & J. Ritter)

AG Seismologie 2017, Bad Breisig: Poster (J. Ritter, KIT)

5th Colloquium on historical earthquake & paleoseismology studies 2018, Hannover: Talk (K. Reicherter)

5th Colloquium on historical earthquake & paleoseismology studies 2018, Hannover: Poster (J. Thomas, RWTH)

AlpArray Meeting 2018, Zürich: Poster (S. Mader, KIT)

AG Seismologie 2018, Pirna: Poster (S. Mader, KIT)

4D-MB SPP Meeting 2018 – Talk (S. Mader, KIT), Poster (Hürtgen, RWTH)

Tectonics, Structural Geology and Crystalline Geology (TSK 17) 2018, Jena: Talk and Poster (RWTH)

9th Paleoseismology, Active Tectonics and Archeoseismology (PATA) days, 2018, Possidi, Greece – Talk (K. Reicherter, RWTH)

6th Colloquium on Historical Earthquake & Paleoseismology Studies 2018, Han sur Lesse, Belgien – Talk (K. Reicherter, RWTH)

Deutsche Geophysikalische Gesellschaft, Jahrestagung, Leoben, Austria 2018: Talk (J. Ritter, KIT)

European Geosciences Union, Vienna, Austria 2018: Talk (J. Ritter, KIT)

Tagung der Arbeitsgemeinschaft Alpenvorlandquartär (AGAQ) 2018, Bad Waldsee: Talks (J. Hürtgen and K. Reicherter, RWTH)

European Geosciences Union, Vienna, Austria 2019: Poster (S. Mader, KIT)

AG Seismologie 2019 – Poster (S. Mader, KIT)

International Union for Quaternary Research (INQUA) 2019, Dublin, Ireland: Talk (K. Reicherter, RWTH)

Colloquium Univ. Freiburg, 5. 2. 2019: Key note (K. Reicherter, RWTH)

Colloquium Karlsruhe Institute of Technology, 7. 2. 2019: Key note (K. Reicherter, RWTH)

IRSN, Paris France, 16. 4. 2019: Key note (K. Reicherter, RWTH)

7th Colloquium on historical earthquake & paleoseismology studies 2019, Barcelona, Spain – Poster (RWTH)

4D-MB SPP Meeting 2019: Talks and Posters (RWTH & KIT)

<u>Abstracts:</u>

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Outreach

Badische Neueste Nachrichten (daily newspaper for Karlsruhe and its wider region): Article on AlpArray, 12. June 2018

Badische Neueste Nachrichten (daily newspaper for Karlsruhe and its wider region): Article on trenching and local earthquakes near Ettlingen, 5. Oct. 2019 plus extended online report: https://bnn.de/lokales/ettlingen/wird-weltweit-ausstrahlen-erdbebenforscher-weisen-naturkatastrophe-bei-ettlingen-nach

Südwestrundfunk (SWR, radio and TV for Southwest Germany): several TV and radio reports on trenching and local earthquakes near Ettlingen, Oct. 2019, also online, e.g.:
1. https://www.swr.de/swraktuell/baden-wuerttemberg/karlsruhe/Spurensuche-in-Ettlingen-Karlsruher-Experten-erforschen-Eiszeit-Erdbeben,erdbeben-106.html
2. https://www.swr.de/swr2/wissen/Erdbeben-Steigt-die-Erdbebengefahr-im-Oberrheingraben,16-steigt-die-erdbebengefahr-im-oberrheingraben-100.html
3. https://www.swr.de/swraktuell/baden-wuerttemberg/karlsruhe/Erdbebenforscher-in-Ettlignen-Oberweier,1159500-100.html

Baden TV (local TV for Baden): Report on trenching near Ettlingen, online: https://baden-tv.com/die-erde-bebt/