Geophysical Institute, KIT-Department of Physics
Hertzstr. 16, 76187 Karlsruhe
www.gpi.kit.edu

Contact for alumni affairs: Kerstin.Dick@kit.edu

NEWSLETTER OF THE GEOPHYSICAL INSTITUTE

DEAR GPI ALUMNI

The last 18 months were a testing period for GPI and as you have seen our loved newsletter got not published as we were focusing to keep the teaching and academic life afloat. Even after nearly two years of pandemic we are still looking into an uncertain future, but we try to give you a brief update on what is happening at the institute. Sadly, Prof. Dr. Karl Fuchs, our former director, passed away this year and you can find the obituary on page 7. Karl was still a regular at our seminars and as the person who shaped GPI to what it is, he will be greatly missed. GPI embraced online teaching and we are now all experts in Zoom, TEAMS, BIgBlueButton you name it.

However, this semester we returned to in person teaching and I must admit it is a real joy for students and lecturers alike. We really hope this can continue! On the research site you can see that GPI was nevertheless very active in many projects as evidenced by our long publication list for the last two years. New projects are continuing and starting all over the world and more information will come in the summer 2022 newsletter.

We wish all our Alumni “Merry Christmas and Happy New Year”, but most importantly stay healthy!

Andreas Rietbrock

AQIFER CHARACTERIZATION USING MULTIPARAMTER MULTICOMPONENT VISCOELASTIC FULL-WAVEFORM INVERSION

By Nikolaos Athanasopoulos, Thomas Bohlen and Anja Klotzsche

Aquifer systems are complex near-surface targets, making their evaluation with non-invasive geophysical methods a challenging task. Aquifers are sedimentary deposits which are often composed of several distinct facies that exhibit large variations in seismic properties. Conventional seismic methods based on the analysis of traveltimes, such as first arrival travel time of refracted P-waves or the dispersion of surface waves, provide P- and S-wave velocity models with limited resolution. Due to this poor resolution many geoscientific studies have excluded the application of seismic surveys for aquifer characterization.

In a collaborative effort with the Institute of Bio- and Geosciences at Forschungszentrum Jülich, the benefits of viscoelastic full-waveform inversion (FWI) are exploited as an effort to improve aquifer characterization for better understanding of its properties and delineating its structure (Athanasopoulos, 2020). We conducted 2D multi-component field measurements of P-SV and SH-waves along two orthogonal profiles at the Jülich acquifer test site Krauthausen, where in-situ information from several boreholes is available to benchmark the reconstructed seismic model.

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For this purpose we constructed a new prismatic source, to achieve additionally better coupling and coherency in the seismic recordings and allow for proper execution of joint inversion of P-SV and SH-waves using data acquired from all three recorded components (P-SV: vertical and horizontal inline, SH: horizontal crossline).

The joint inversion of P-SV and SH waves revealed a thin S-wave low-velocity layer below the ground water table (Figure 1). Furthermore, a high correlation of the density model with in-situ borehole information also observed. Overall, it could be verified that FWI of shallow seismic surfaces waves can produce models of S-wave velocity with very high resolution.

The density models showed surprisingly high correlation with in-situ CPT data.

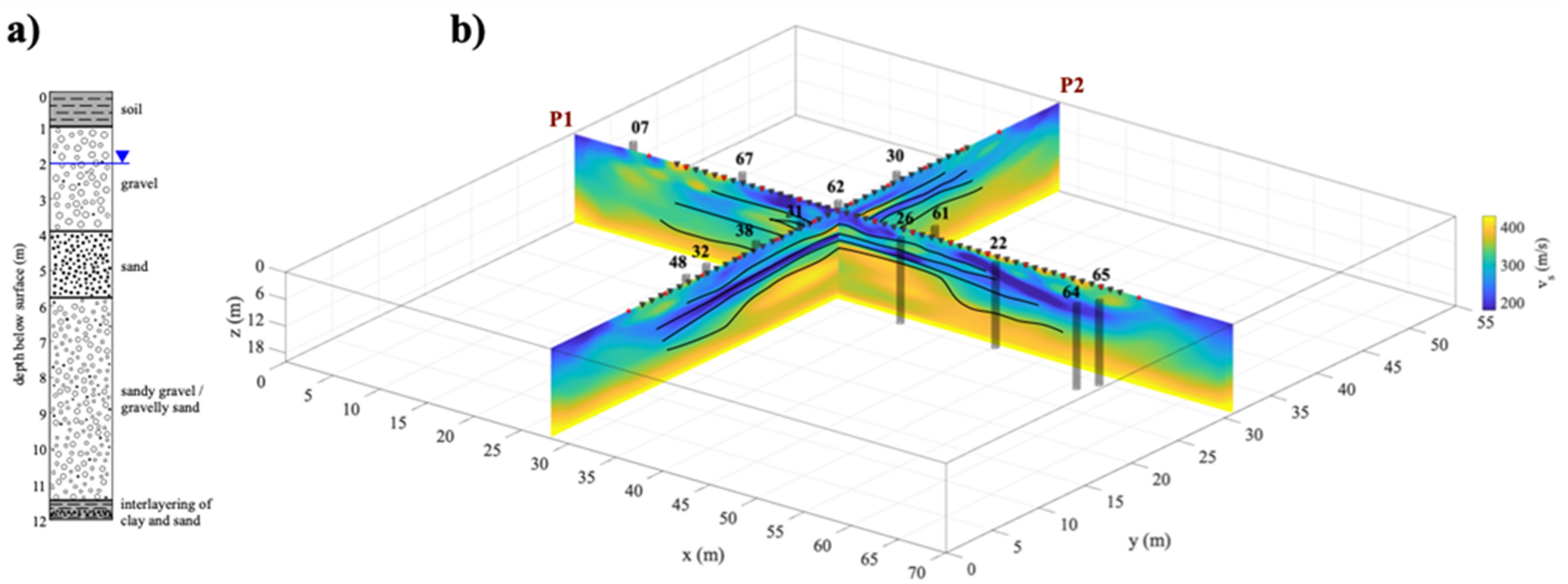

Figure 1: a) A conceptual model of the geologic sequence for the aquifer in Krauthausen. b) 3D plot of the retrieved S-wave velocity model from joint FWI of Rayleigh and Love waves of the two profiles. Black (opal) cylinders represent the boreholes in the area that were used to perform crosshole ground-penetrating radar (GPR) FWI by the research group in Jülich. The solid lines mark the geological boundaries from the interpretation of the resulted elastic parameters.

Athanasopoulos, N. (2020) *Challenges in near-surface seismic full-waveform inversion of field data.* PhD thesis, Karlsruher Institut für Technologie (KIT).

Karlsruhe Institute of Technology

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ACTIVE SEISMIC EXPERIMENT AT THE OCHTENDUNG FAULT ZONE

By Andreas Rietbrock and Joachim Ritter

Last summer we installed a new seismological experiment across the Ochtendung Fault Zone (OFZ), see newsletter July 2020. The OFZ is a continuously active fault which produces felt earthquakes about once per year (*ML* up to ~3.5) and weekly minor events (*ML* ~1). We had deployed 17 seismic recording stations along a 5 km long field track in a joint effort of GPI, RWTH Aachen and Seismological Service Mainz. After several postponements due to the Covid pandemic we finally conducted an active source campaign together with our partners from Aachen, Mainz, and Potsdam in June 2021. Using 200 field recorders and seismometers together with an accelerated weight drop from the Geophysical Instrument Pool at GFZ Potsdam about a 4.5 km long line was investigated.

The station spacing was 5 m and shots were fired at 25 m distance with 4-5 stacks. The GPI team consisted of A. Rietbrock, B. Braszus, J.-P. Föst, M. Frietsch, L. Merkel, and J. Ritter.

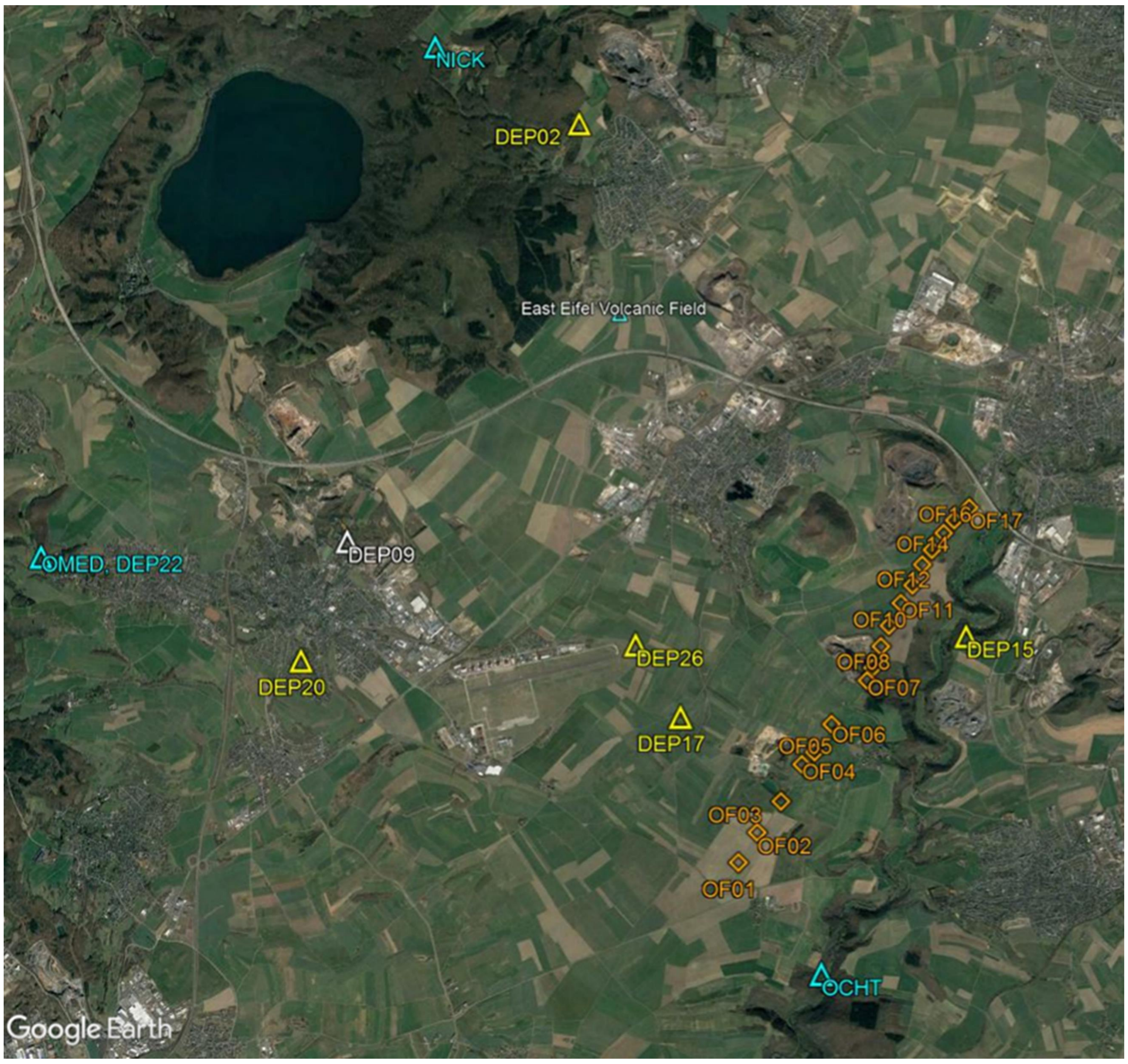

Figure: Map of the region with the Laacher See Volcano (top left) and the seismic stations from several networks. The orange symbols belong to the Ochtendung Fault Zone Seismological Experiment.

Photo: J. Ritter

Figure: Impressions from the field work in the Eifel.
Photo: J. Ritter

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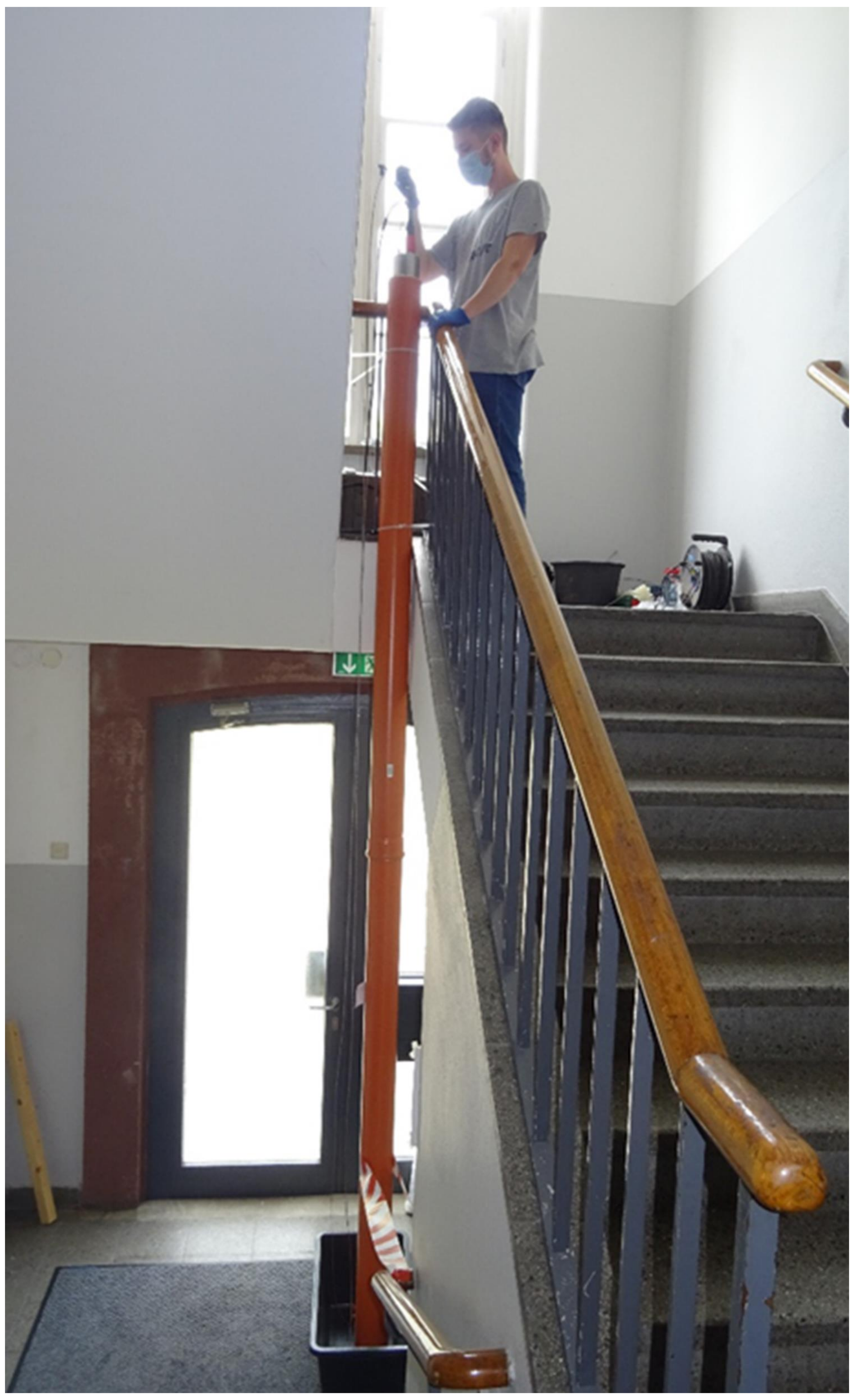
BOREHOLE SEISMOMETERS AT WINSENT TESTFILED

By Joachim Ritter

GPI is involved in the test field for wind energy turbines called WINSENT (https://www.windfors.de/de/projekte/testfeld/winsent/). The test field is built near Stötten on the Swabian Alb close to Geislingen a.d. Steige. After numerous quarrels since the last 4 years incl. lawsuits, we could finally start with the installation of the three borehole seismometers. Three 5 m deep holes were drilled and 20 s Nanometrics Posthole Seismometers were installed. For training, a tube was installed in building 6.42 where we could test the handling of the instrument. The GPI field team consisted of F. Bögelpacher, M. Gärtner, L. Merkel, and J. Ritter.



Figures: Four-meter high tube for borehole simulation at GPI. A bowl at the bottom collects the glass beads inside the tube. In the field the instruments are protected with a buried concrete housing, the seismometer hole is covered with a plastic bag.

Photo: J. Ritter

PLATE TECTONICS: FORMATION OF THE CARIBEAN

By Andreas Rietbrock and Benedikt Braszus

Scientists from KIT and their international collaborators uncovered one of the last "white spots" in the global plate tectonic puzzle (published in Nature Comm.)

Be it strong earthquakes or violent volcanic eruptions, the Caribbean is often rocked by disastrous hazards triggered by the motions of the Earth's tectonic plates. A team of international scientists including from the Karlsruhe Institute of Technology (KIT) now obtained a new understanding of how plate-tectonics in the Caribbean evolved. Their results have just been published in the journal Nature Communications.
"The Caribbean Plate is surrounded by three other plates. As a result, the region is very seismically active. Nonetheless, there is no agreement to date on how and when the Caribbean was formed." says Andreas Rietbrock, director of the Geophysical Institute (GPI) of the KIT. In the international project "VoiLA – Volatile Recycling in the Lesser Antilles", geophysicists from the GPI analysed data from state-of-the-art ocean-bottom seismometers and used these data to generate tomographic images of the upper part of Earth's mantle down to about 700 km depth. In combination with a reconstruction of global plate motions over the last 120 million years, analysed by partners from Imperial College London, they could interpret the images: "The tomography shows the tectonic plates that have sunk below the present-day Caribbean Ocean", says Benedikt Braszus, Masters student in geophysics at the KIT and first author of the paper. "Using the plate reconstruction, we could determine where and when these plate fragments sank into the interior of the Earth, and with that information we could unravel the motions at the plate boundaries surrounding the Caribbean over the past 100 million years". This will allow, as a next step, the most detailed and comprehensive description of how the Caribbean formed.

Figure: Deep in the Caribbean: against the backdrop of the volcanic island of Montserrat, the seismometers are brought back on board. Foto: Stephen P. Hicks

KARL FUCHS 1932-2021

Prof. Dr. Karl Fuchs, our former director, shaped the GPI as we know it now. He was a world-wide leading geophysicist and strengthened the international reputation of GPI. Karl pushed GPI activities such as the Rhinegraben Seismic Network, the Black Forest Observatory, the international seismic campaigns and the stress map project. He also initiated many international and interdisciplinary research programs, served in international boards and published about 100 peer-reviewed papers. Karl passed away on 22nd March 2021 after a short illness.

Karl in 2019

Foto: private

Karl was born on 21. January 1932 in Stettin, now Szczecin, Poland. After World War II his family fled to Germany where he went to school near Hamburg. He studied geophysics in Hamburg, London, and Clausthal. In 1957 he finished his studies in Clausthal and married his wife Cornelia (to many known as Corry).

Karl accepted a position in the oil exploration industry and worked for Prakla Seismos G.m.b.H. (Hannover) as leader of geophysical field crews in the Amazonas Basin in Brazil and the Sahara Desert in Algeria. Two years later he returned to Clausthal to pursue a PhD. Karl planned and organised long-range seismic refraction campaigns in Central Europe to explore the crust and uppermost mantle. He carefully analysed the seismic records and also started theoretical work on wave propagation.

In 1963 Karl completed his dissertation on ‘Investigations on the wave propagation in wedge shaped media’ – a starting point for the famous reflectivity method to calculate synthetic seismograms. Afterwards he held postdoc positions in Clausthal, Saint Louis, and Dallas.

In 1965 Prof. Stephan Mueller offered him a position in the newly founded Geophysical Institute at the University of Karlsruhe. Karl accepted and started in October 1965. He would stay in Karlsruhe for the rest of his life. In the beginning Karl was responsible for the branch Applied Geophysics and worked on deep seismic sounding and numerical wave propagation. He submitted his habilitation thesis on ‘The reflexion of spherical waves at inhomogeneous transition zones with arbitrary depth distribution of the elastic moduli and the density’ in 1968 and became a member of the faculty.

After Stephan Mueller had changed to ETH Zürich, Karl accepted the chair of General Geophysics in Karlsruhe in 1971, while he also had another offer from Berlin. After his retirement he played an active role in advising the newly established Collaborative Research Center 416 on Strong Earthquakes and worked on historical events such as the 1755 Lisbon earthquake. He kept visiting US Institutions such as Stanford University and the USGS and attended most institute seminars until Corona stopped the physical presence of participants.

Karl's main achievement in theoretical geophysics was the establishment of the reflectivity method to compute synthetic seismograms partly in collaboration with Gerhard Müller. He implemented a computer code on the first mainframes and was able to compute full seismograms in layered media representing the lithosphere. In this way he consistently combined his theoretical and computational work with the application to deep seismic sounding. Thereby he became a leading scientist in studying lithospheric structures and the upper mantle in the 1960s – 1980s. He also went a step further and started petrophysical interpretations of seismic models.

He initiated numerous field measurements for long-range seismic profiles in international collaboration. One focus was on continental rift systems: as Karlsruhe is situated in the Upper Rhine Graben, first studies started here in the late 1960. Later the Dead Sea region and the Kenya Rift were investigated with international partners. In the 1980s and 1990s his focus shifted to the understanding of the stress field of the lithosphere (World Stress Map) and earthquake hazard projects. He started and led the successful Collaborative Research Centre 108 'Stress and Stress Release in the Lithosphere' in Karlsruhe and became president of the International Lithosphere Program (ILP). After the cold war Karl initiated joint research projects for eastern and western countries under the umbrella of the EUROPROBE programme of the European Science Foundation.

Karl and Corry Fuchs at a reception in 1995. Foto: private

PhD at GPI

In October 2020 M.Sc. **Sergio Leon-Rios** successfully defended his PhD thesis.

Title: 3D TOMOGRAPHY BASED ON THE AFTERSHOCK SEQUENCE OF THE 2016 MW 7.8 PEDERNALES, ECUADOR EARTHQUAKE

Supervisors:
Prof. Dr. Andreas Rietbrock (KIT)
Apl. Prof. Dr. Joachim Ritter (KIT)

Based on manually analyzed waveforms recorded by the permanent Ecuadorian network and our large aftershock deployment installed shortly after the 2016 Mw 7.8 Pedernales earthquake, I derive three-dimensional *Vp* and *Vp/Vs* structures and earthquake locations for central coastal Ecuador using local earthquake tomography.

Images highlight the features in the subducting and overriding plates down to 35 km depth. The *Vp* anomalies show the roughness of the incoming oceanic crust. On the other hand, the *Vp/Vs* ratios are consistent with terranes of oceanic nature. We identify several features that might play an important role in controlling the seismic behavior of the margin. While subducted seamounts might contribute to the nucleation of intermediate megathrust earthquakes in the northern segment, the Carnegie Ridge, a large submarine mountain chain, seems to be the main feature controlling the seismicity in the region by promoting creeping and slow slip events offshore that can be linked to the updip limit of large megathrust earthquakes in the northern segment and the absence of them in the southern region over the instrumental period.

This study contributes to a better understanding of the processes occurring in subduction zones. Especially, I remark the importance of having a complete seismic velocity structure that includes both *Vp* and *Vp/Vs* ratios which complement with each other in order to give a full interpretation for the features observed along the studied margin. Furthermore, the analysis of the seismic velocities of the rocks along the seismic interface, together with information derived from geodetic studies and the rupture area grid search approach designed in this work, can provide valuable data neccesary for the estimation of seismic hazard.

Articles:

1D-velocity structure and seismotectonics of the Ecuadorian margin inferred from the 2016 Mw7. 8 Pedernales aftershock sequence. Leon-Rios et al., 2019. *Tectonophysics*.
3D local earthquake tomography of the Ecuadorian margin in the source area of the 2016 Mw 7.8 Pedernales earthquake. Leon-Rios et al., 2020.

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In November 2020 M.Sc. Nikolaos Athanasopoulos successfully defended his PhD thesis.

Title: Challenges in near-surface seismic full-waveform inversion of field data

Supervisors:
Prof. Dr. Thomas Bohlen (KIT)
Prof. Dr. Hansruedi Maurer (ETH Zürich)

His research contributes to developments in modeling and inversion of shallow seismic data, through the development of sophisticated strategies and frameworks in the context of full-waveform inversion (FWI). The application of seismic FWI from 3-component shallow seismic data is demonstrated here for the first time. Both synthetic and field studies are examined and reveal the benefits of multicomponent data for multiparameter FWI. The challenges that arise in such geophysical targets are discussed and methodologies to overcome these challenges are implemented and tested in the FWI framework. The target areas consist of a near-surface survey on an archaeological test site near Karlsruhe and the structural characterisation of an aquifer system near Jülich.

https://doi.org/10.5445/IR/1000126528

NEW PhD CANDIDATES

On 1st January, Yvonne Fröhlich started her PhD project. Yvonne received a grant from the Landesgraduiertenförderung. She studies deep seismic anisotropy in the Upper Rhine Graben region using shear wave splitting of teleseismic phases (SKS, SKKS).

Benedikt Braszus started in autumn 2020 his PhD project on LET for the Alpine Orogeny founded by the DFG.

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RECENT PUBLICATIONS

In this section we would like to inform about recently published peer-reviewed journal papers authored by current members of GPI:

Grund M., Ritter, J.R.R.: Shear-wave splitting beneath Fennoscandia - Evidence for dipping structures and laterally varying multi-layer anisotropy. *Geophys. J. Int.* , 223, 1525-1547, 2020.

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Leon-Rios, S., Bie, L., Agurto-Detzel, H., Rietbrock, A., Galve, A., Alvarado, A., et al.. 3D local earthquake tomography of the Ecuadorian margin in the source area of the 2016 Mw 7.8 Pedernales earthquake. Journal of Geophysical Research: Solid Earth, 126, e2020JB020701, 2021. https://doi. org/10.1029/2020JB020701

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Geophysical Institute, KIT-Department of Physics
Hertzstr. 16, 76187 Karlsruhe
www.gpi.kit.edu

Contact for alumni affairs: Kerstin.Dick@kit.edu

We hope everyone has a wonderful holiday season and a happy new year!