

# Living on a Restless Earth

## Newsletter

October 2023 | #2



## News

### EU-funded project SUBMERSE has started

The new EU project SUBMERSE (SUBMarine cables for ReSearch and Exploration) started on May 1, 2023. The project aims to use already existing submarine telecommunication cables as sensors to monitor e.g. earthquakes, volcanoes or the ocean. SUBMERSE is a collaboration of 18 partner institutions, five affiliated and one associated partner and is coordinated by the European Future Innovation System (EFIS) Centre. Frederik Tilmann from GFZ Section 2.4 is leading work package 3 that especially focuses on the geoscientific use of the cables.

More information:

<https://submerse.eu/>

### New PhD network “TALENTS” starts in 2024

The Marie Skłodowska-Curie PhD network “TALENTS: The doctoral rift science network for the energy transition” was accepted in March 2023. Sascha Brune from GFZ section 2.5. will coordinate the network together with Susanne Buiter and others. Starting in January 2024, 12 doctoral researchers in nine European institutions will have the chance to study the initiation and evolution of rifts with an emphasis on geohazards (Topic 3) and georesources (Topic 8).

More information:

<https://www.gfz-potsdam.de/en/press/news/details/maerz-2023-neues-marie-sklodowska-curie-doktorandennetzwerk>

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# Recent workshops and training activities

## International training course on seismology and seismic hazard assessment

From June 21 to July 19, 2023 the UNESCO training course „Seismology, Seismic Data Analysis, Hazard Assessment and Risk Mitigation“ was taking place at the Telegrafenberg in Potsdam. For 22 participants from 18 developing countries or countries in transition the course provided theoretical knowledge and practical training on topics like seismic sources, site effect estimation, seismic sensors, seismological software, seismic hazard and risk assessment and satellite methods. Experts from GFZ Sections 2.1, 2.4, 2.6 and 1.4 and scientist from other German and European institutions were contributing to the program. The next training course will take place in Podgorica, Montenegro from October 9 to 23, 2023.

More information:

<https://www.gfz-potsdam.de/en/about-us/education-and-training/seismology-and-hazard-assessment>



*Course participants and lecturers of the 2023 UNESCO training course on "Seismology and Seismic Hazard". (Photo: GFZ)*

## International training course on ocean bottom seismology

On July 12 and 13, 2023, 21 early career scientist from several countries joined the 'International training course on ocean bottom seismology and amphibian experiment seismological data' taking place at the GFZ Potsdam. The participants learned how to access and use ocean bottom and amphibian pool data and how to apply novel processing techniques. The course was organized by GFZ, AWI, and the University of Potsdam.

More information:

<https://www.gfz-potsdam.de/en/press/news/details/internationaler-schulungskurs-zu-seismologischen-daten-von-amphibischen-experimenten-am-gfz>



*Participants and lecturers of the Training course on cean bottom seismology. (Photo: Rosa Dishur, GFZ)*

## **Workshop on ‘Selected Topics in Space Physics’**

From July 11-12, 2023 scientist from Germany, the United States, China and the Czech Republic met at GFZ Potsdam to foster the interplay between various subsets within space physics. The presentations covered topics from ionospheric, magnetospheric, solar and solar wind physics. The following discussion accentuated the interconnectivity between these distinct subdomains and the participants identified outstanding questions, methodological approaches and overarching themes.



*Participants of the Workshop on "Selected Topics in Space Physics". (Photo: GFZ)*

## **Ocean volcanism workshop**

Under the motto ‘Stronger together’ 85 scientist from all over the world met at GEOMAR in Kiel and discussed submarine volcanoes and how they affect our lives. From September 12-15, the participants could show their projects and results, report from expeditions and discuss possible new cooperations. The workshop was organized by the Commission on Submarine Volcanism (CosV) of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) and the GEOMAR Helmholtz Centre for Ocean Research Kiel.



More information:

<https://www.geomar.de/en/news/article/allianzen-schmieden-fuer-die-marine-vulkanologie>



*Participants of the Ocean Volcanism workshop at GEOMAR (Photo: Samuel J. Mitchell, Bristol University)*

## **ICDP conference at GFZ**

In July 2023, the International Continental Drilling Programme ICDP celebrated its 25+2 years anniversary at the GFZ in Potsdam. 139 participants from 23 countries joined the IV. "International Conference of Continental Scientific Drilling: ICDP in the Second Quarter of its First Century". The invited guests of the conference presented highlights of past drilling activities and discussed the future and programmatic orientation of the ICDP that is currently under the lead of the head of Section 4.2, Marco Bohnhoff.

More information:

<https://www.gfz-potsdam.de/en/press/news/details/nachlese-icdp-konferenz-am-gfz>



*Participants of the ICDP conference at Potsdam. (Photo: Thomas Wiersberg, GFZ/ICDP)*

# Expeditions and Activities

## Expedition to study the flank collapse of the Anak Krakatau



Anak Krakatau as seen from board of the RV Sonne. Photo: Jonas Preine (University of Hamburg)

From August 15 to September 2, 2023, Prof. Morelia Urlaub (GEOMAR) lead the expedition SO299/2 with the title “REE-T”: “Reconstruction of Eruptions and Volcanic Tsunamis at Krakatau Volcano”. The 16 researchers on board investigated the deposits of the 2018 landslide and the pyroclastic flows from the historic 1883 eruption using e.g. seismic reflection profiling, sediment coring and photogrammetric drone surveys. The goal of the expedition was to better understand the functioning of the Krakatau/Anak Krakatau system through time, and to get insides

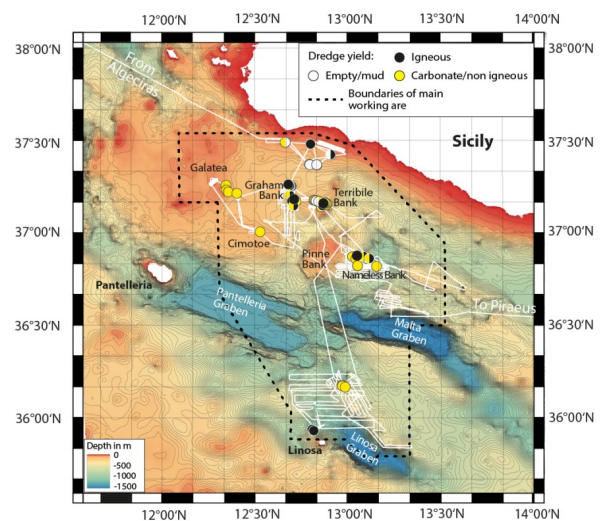
into the cascade of flank collapse and tsunami generation. The expedition was part of Prof. Morelia’s ERC project PRE-COLLAPSE “Slow sliding of volcanic flanks as PREcursor to catastrophic COLLAPSE” where she and her team study four island volcanoes having flanks that are at risk to collapse.

More information:

<https://www.geomar.de/en/news/article/rare-but-devastating-when-volcanoes-trigger-tsunamis>

## SUAVE expedition reveals new volcanic structures in the Mediterranean Sea

From July 16 to August 5, 2023, an international team of scientist lead by Jörg Geldmacher from GEOMAR mapped the seafloor along the Sicilian Channel Rift Zone in the Mediterranean. The goal of the the METEOR M191 expedition (Submarine volcanism in the western Sicilian Channel, SUAVE) was to map volcanic structures and to investigate the origin and role of volcanism in passive continental rifts. Using multibeam echosounders and magnetometers, the scientists revealed three volcanic centres and a ship wreck. Lava samples were taken from the submarine volcanoes and will be analysed in



Working area of the SUAVE expedition. Figure from the Short Cruise Report R/V METEOR cruise M191 (GPF 21-1\_036).

the laboratory. They will give insight on the age and the source of the magma feeding.

More information:

<https://www.geomar.de/news/article/suave-bringt-neue-entdeckungen-im-mittelmeer>

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## Scientific Highlights

### Variation of fault creep along the overdue Istanbul-Marmara seismic gap in NW Türkiye

**Abstract** Strain energy from tectonic loading can be partly released through aseismic creep. Earthquake repeaters, repeatedly activated brittle fault patches surrounded by creep, indicate steady-state creep that affects the amount of seismic energy available for the next large earthquake along a plate contact. The offshore Main Marmara Fault (MMF) of the North Anatolian Fault Zone represents a seismic gap capable of generating a  $M > 7$  earthquake in direct vicinity to the mega-city Istanbul. Based on a newly compiled seismicity catalog, we identify repeating earthquakes to resolve the spatial creep variability along the MMF during a 15-year period. We observe a maximum of seismic repeaters indicating creep along the central and western MMF segments tapering off toward the locked onshore Ganos fault in the west, and the locked offshore Princes Islands segment immediately south of Istanbul in the east. This indicates a high degree of spatial creep variability along the Istanbul-Marmara seismic gap.

Becker, D., Martínez-Garzón, P., Wollin, C., Kılıç, T., & Bohnhoff, M. (2023). Variation of Fault Creep Along the Overdue Istanbul-Marmara Seismic Gap in NW Türkiye. *Geophysical Research Letters*, 50(6), e2022GL101471, <https://doi.org/10.1029/2022GL101471>.

### Spatio-temporal variations of seismic coupling along a transform fault: the western North Anatolian Fault Zone

**Abstract** The Main Marmara Fault (MMF) forms a major segment of the North Anatolian Fault Zone (NAFZ) in northwestern Türkiye. The MMF represents a seismic gap with currently high seismic hazard and associated risk for the Istanbul metropolitan area. Here we estimate the seismic coupling defined as the ratio of the seismic strain rate to the tectonic strain rate, for the MMF and adjacent NAFZ segments. This ratio indicates the fraction of total strain accumulated with time that is released seismically. We compare the results of seismic strain rates and coupling estimated from earthquakes included in historical and instrumental catalogues, which allows us to identify fault segments that represent a considerable seismic threat during the current seismic cycle. We find that along the main fault traces hosting the large events, seismic strain rates from the historical



catalogue are of the same order as the tectonic strain rates. In contrast, coupling estimates based on seismic data from the instrumental catalogue covering also off-fault areas, are up to 100 times smaller, highlighting that most of the seismic energy is released in large earthquakes with recurrence times longer than the time covered by the instrumental catalogue. Within the Sea of Marmara, a significant portion (48%) of shear strain from the instrumental catalogue is currently being accommodated by seismic deformation. Significant variations of the seismic coupling are observed before and after the 1999  $M > 7$  Izmit earthquake, highlighting the different contribution of aseismic slip over different portions of the seismic cycle. A comparison of the temporal evolution of the 1999 Izmit and Düzce post-seismic deformation with seismic strain rates shows that the largest seismic strain rates coincide with the largest post-seismic deformation.

**Amemoutou, A., Martínez-Garzón, P., Durand, V., Kwiatek, G., Bohnhoff, M., & Dresen, G. (2023).** Spatio-temporal variations of seismic coupling along a transform fault: the western North Anatolian Fault Zone. *Geophysical Journal International*, 235(2), 1982-1995, <https://doi.org/10.1093/gji/ggad341>.

## **Impact of the Iquique Ridge on the structure and deformation of the north Chilean subduction zone**

**Abstract** The subduction of seamounts and basement ridges affects the structure, morphology, and physical state of a convergent margin. To evaluate their impact on the seismo-tectonic setting of the subduction zone and the tectonic development of the lower subducting and upper overriding plate, it is essential to know the precise location of subducted topographic features under the marine forearc. Offshore Northern Chile, the Iquique Ridge represents a broad zone of complex and heterogeneous structure of variable width on the oceanic Nazca Plate, which complicates attempts to project it beneath the forearc of the Chilean subduction zone. Here we use a state-of-the-art seismic reflection data processing approach to map structures related to ridge subduction under the marine forearc with unprecedented accuracy and resolution and evaluate their impact on the deformation of both the plate boundary and the upper plate. We show that significant ridge-related topography is currently subducting south of 20.5 °S and that the combined effect of horst and graben subduction with subduction of Iquique ridge-related thickened and elevated crust causes an upward bulging of the entire upper plate from the plate interface up to the seafloor as well as the presence of kilometer-scale anticlinal structures observed in multibeam bathymetric data that are approximately aligned with horsts seaward of the trench. In the area affected by the subducting ridge, a frontal prism is absent, which may relate to frontal subduction erosion caused by the excess lower plate topography. In contrast farther towards the north, where only isolated seamounts subduct, a small frontal prism and a slope/apron sediment cover down to 3000 m water depth are found.

**Ma, B., Geersen, J., Klaeschen, D., Contreras-Reyes, E., Riedel, M., Xia, Y., Tréhu, A.M., Lange, D. & Kopp, H. (2023).** Impact of the Iquique Ridge on structure and deformation of the north Chilean subduction zone. *Journal of South American Earth Sciences*, 124, 104262, <https://doi.org/10.1016/j.jsames.2023.104262>.

## Formation of undulating seafloor bedforms during the Minoan eruption and their implications for eruption dynamics and slope stability at Santorini

**Abstract** The Minoan eruption of Santorini is one of the largest Holocene volcanic events and produced several cubic kilometers of pyroclastic flows emplaced on the submerged flanks of the volcano. Marine geophysical surveys reveal a multitude of undulating seafloor bedforms (USBs) around Santorini. While similar structures are known from other volcanoes worldwide, Santorini offers the unique opportunity to relate USB formation with volcanic processes during one of the best-studied volcanic eruptions worldwide. In this study, we combine high-resolution seismic reflection data with multibeam echosounder bathymetry to reveal the internal architecture of USBs around Santorini and to relate their morphological characteristics to formational processes. The USBs around Santorini were formed during the Minoan eruption and represent the seafloor expression of mass transport deposits. Three types of deposits differ in composition or origin. (1) Depositional USBs, which can only be found to the north of the island, where Minoan eruption ignimbrites reach their maximum thickness and the undulating topography is the result of thrusting within the deposit. (2) USBs related to slope failures of volcanoclastics from the entire Thera Pyroclastic Formation, which can be found east, south, and west of the island. (3) USBs associated with deep-seated deformation, which occurs on the southwestern flank along an area affected by rift tectonics and extends to a depth of more than 200 m below the seafloor. In cases (2) and (3), the USBs are formed upslope by block rotation and downslope by thrusting. Our study indicates that these processes may have contributed to the generation of the devastating Minoan tsunami. Since Santorini is located in one of the most tectonically active regions in the Mediterranean, capable of producing earthquakes with magnitude M7+, our study has important implications for hazard assessment. A strong earthquake located close to the island may have the potential to reactivate slope instabilities posing a previously undetected but potentially significant tsunami hazard.

**Karstens, J.**, Preine, J., Carey, S., Bell, K. L., Nomikou, P., Hübscher, C., Lampridou, D. & **Urlaub, M.** (2023). Formation of undulating seafloor bedforms during the Minoan eruption and their implications for eruption dynamics and slope stability at Santorini. *Earth and Planetary Science Letters*, 616, 118215, <https://doi.org/10.1016/j.epsl.2023.118215>.

## Rift-induced disruption of cratonic keels drives kimberlite volcanism

**Abstract** Kimberlites are volatile-rich, occasionally diamond-bearing magmas that have erupted explosively at Earth's surface in the geologic past. These enigmatic magmas, originating from depths exceeding 150 km in Earth's mantle, occur in stable cratons and in pulses broadly synchronous with supercontinent cyclicity. Whether their mobilization is driven by mantle plumes or by mechanical weakening of cratonic lithosphere remains unclear. Here we show that most kimberlites spanning the past billion years erupted about 30 million years (Myr) after continental breakup, suggesting an association with rifting



processes. Our dynamical and analytical models show that physically steep lithosphere–asthenosphere boundaries (LABs) formed during rifting generate convective instabilities in the asthenosphere that slowly migrate many hundreds to thousands of kilometres inboard of rift zones. These instabilities endure many tens of millions of years after continental breakup and destabilize the basal tens of kilometres of the cratonic lithosphere, or keel. Displaced keel is replaced by a hot, upwelling mixture of asthenosphere and recycled volatile-rich keel in the return flow, causing decompressional partial melting. Our calculations show that this process can generate small-volume, low-degree, volatile-rich melts, closely matching the characteristics expected of kimberlites. Together, these results provide a quantitative and mechanistic link between kimberlite episodicity and supercontinent cycles through progressive disruption of cratonic keels.

Gernon, T. M., Jones, S. M., **Brune, S.**, Hincks, T. K., Palmer, M. R., Schumacher, J. C., Primiceri, R. M., Field, M., Griffin, W. L., O'Reilly, S. Y., Keir, D., Spencer, C. J., Merdith, A. S. & **Glerum, A.** (2023). Rift-induced disruption of cratonic keels drives kimberlite volcanism. *Nature*, 1-7, <https://doi.org/10.1038/s41586-023-06193-3>.

## Criteria-based visualization design for hazard maps

**Abstract** Probabilistic seismic hazard estimates are a key ingredient of earthquake risk mitigation strategies and are often communicated through seismic hazard maps. Though the literature suggests that visual design properties are key for effective communication using such maps, guidelines on how to optimally design hazard maps are missing from the literature. Current maps use color palettes and data classification schemes which have well-documented limitations that may inadvertently miscommunicate seismic hazard. We surveyed the literature on color and classification schemes to identify design criteria that have empirical support for communicating hazard information. These criteria were then applied to redesign the seismic hazard map for Germany. We established several communication goals for this map, including essential properties about moderate-hazard seismic regions and a critical hazard threshold related to the German seismic building codes. We elucidate our redesign process and the selection of new colors and classification schemes that satisfy the evidence-based criteria. In a mixed-methods survey, we evaluate the original and redesigned seismic hazard maps, finding that the redesign satisfies all the communication goals and improves users' awareness about the spatial spread of seismic hazard relative to the original. We consider practical implications for the design of hazard maps across the natural hazards.

Schneider, M., **Cotton, F.**, & **Schweizer, P.-J.** (2023), Criteria-based visualization design for hazard maps. *Nat. Hazards Earth Syst. Sci.*, 23, 2505–2521, <https://doi.org/10.5194/nhess-23-2505-2023>.

## Global geomagnetic field evolution from 900 to 700 ka including the Matuyama-Brunhes reversal

**Abstract** Polarity reversals and excursions are the most significant geomagnetic field changes generated in the liquid outer core of the Earth, therefore studying them helps

understand geodynamo processes. This study examines the Matuyama-Brunhes (MB) reversal using a new reconstruction of the global geomagnetic field based on paleomagnetic data, termed Global Geomagnetic Field Model for the MB reversal (GGFMB). GGFMB covers 900–700 ka, including late Matuyama and early Brunhes. This allows us to also investigate the Kamikatsura excursion (ca. 888 ka). The model is based on 38 high-quality paleomagnetic sediment records with age control mostly independent of the magnetic signal. GGFMB suggests that the MB reversal began about ~799 ka, when non-dipole field components increased and the axial dipole component decreased. The transitional fields first appeared on Earth's surface in the high-latitude southern hemisphere and equatorial regions. The minimum dipole strength was reached around 780 ka and the axial dipole changed sign. After ~10 Kyr, the field stabilized in the normal polarity of the early Brunhes. The MB reversal lasted ~29 Kyr (from 799 to 770 ka) and had slower rate of dipole decay than recovery as well as lower dipole moment for several millennia before than after the reversal. According to GGFMB, the dipole moment during the Kamikatsura excursion was approximately half that of the current field and it was a regional excursion observed only over eastern Asia and North America. Our sediment data collection is heavily biased toward the northern hemisphere, thus more southern hemisphere records are needed to demonstrate GGFMB's robustness in this region.

**Mahgoub, A. N., Korte, M., & Panovska, S.** (2023). Global geomagnetic field evolution from 900 to 700 ka including the Matuyama-Brunhes reversal. *Journal of Geophysical Research: Solid Earth*, e2023JB026593, <https://doi.org/10.1029/2023JB026593>.

## **Investigating the Eastern Alpine-Dinaric transition with teleseismic receiver functions: Evidence for subducted European crust**

**Abstract** The tectonic structure of the Eastern Alps is heavily debated with successive geophysical studies that are unable to resolve areas of ambiguity (e.g., the presence of a switch in subduction polarity and differing crustal models). In order to better understand this area, we produce a high resolution Moho map of the Eastern Alps based on a dense seismic broadband array deployment. Moho depths were derived from joint analysis of receiver function images of direct conversions and multiple reflections for both the SV (radial) and SH (transverse) components, which enables us to map overlapping and inclined discontinuities. We observe the European Moho to be underlying the Adriatic Moho from the west up to the eastern edge of the Tauern Window. East of the Tauern Window, a sharp transition from underthrusting European to a flat and thinned crust associated with Pannonian extension tectonics occurs, which is underthrust by both European crust in the north and by Adriatic crust in the south. The Adriatic lithosphere underthrusts northward below the Southern Alps and becomes steeper and deeper towards the Dinarides where it dips towards the north-east. Our results suggest that the steep high velocity region in the mantle below the Eastern Alps, observed in tomographic studies, is likely to be of European origin.

Mroczek, S., Tilmann, F., Pleuger, J., Yuan, X., Heit, B., Swath-D Working Group, & AlpArray Working Group. (2023). Investigating the Eastern Alpine–Dinaric transition with teleseismic receiver functions: Evidence for subducted European crust. *Earth and Planetary Science Letters*, 609, 118096, <https://doi.org/10.1016/j.epsl.2023.118096>.

## Empirical shaking scenarios for Europe: a feasibility study

**Abstract** We process a large number of seismic recordings in Europe (i.e. about half a million recordings from about 19 500 earthquakes) with the aim of decomposing the Fourier amplitude spectra into source, propagation and site effects. To account for first-order, large-scale regional differences in propagation effects, the spectral decomposition simultaneously solves six different models describing the spectral attenuation within different subregions. Since the decomposition approach is affected by trade-offs that make the solution non-unique, we assume a station installed on rock in Switzerland as reference station and we invert for relative site amplifications. To propagate the reference site condition to the entire data set, we develop a procedure based on a sequence of decompositions considering increasing and overlapping data sets. The applied procedure allows for a consistent evaluation of relative site effects for about 3200 station channels using a single reference station for the whole data set. Comparisons with site amplifications obtained in previous studies at common stations in Italy and Switzerland confirm the site amplification results. The target of this work is to show that the spectral models obtained for attenuation and site effects can be used to generate empirical shaking scenarios in the Fourier domain. Therefore, we conclude our feasibility study by presenting shaking maps generated at different frequencies for hypothetical magnitude 6.5 earthquakes with a Brune-type stress drop of 10 MPa located at different positions across Europe.

Bindi, D., Zaccarelli, R., Razafindrakoto, H. N. T., Yen, M-H., & Cotton, F. (2023). Empirical shaking scenarios for Europe: a feasibility study. *Geophysical Journal International*, 232(2), 990-1005, <https://doi.org/10.1093/gji/ggac382>.

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## Awards and Grants

**Dr. Hayley Allison** (formerly at GFZ) receives the Karl Scheel-Prize which is the highest award of the Berlin Physical Society. Dr. Allison is recognized for her work on ultra-relativistic electrons that are trapped by the Earth magnetic field in the radiation belt of the near-Earth space environment. She is the first GFZ researcher receiving this prize.

**Dr. Minghui Xu** (GFZ) wins a Starting Grant of the European Research Council (ERC) for his project “Astrogeodesy”. The grant will help him to improve the performance of the next-generation geodetic VLBI system called VLBI Global Observing System (VGOS).



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# Upcoming workshops and seminars

## 26 October, 2023

### **GFZ-internal workshop “Evolution of the Earth System from the Early Earth to the Quaternary”**

Time and place: 26 October, 2023, 9 am to 4 pm at GFZ Potsdam, house H

The workshop is about geological archives and how they allow us to reconstruct the evolution of the Earth system over timescales from years to hundreds of millions of years.

Contact persons are: Sarah Gleeson, Dirk Sachse, Joe Magnall, Partick Frings, Kai Mangelsdorf, Christian Hallmann and Rik Tjallingii.

## 27 November, 2023

### **Topic 3/Topic 8 seminar talk by Prof. Ioannis Stefanou (Ecole Centrale de Nantes)**

The talk will be about Prof. Stefanou’s ERC project “Controlling earthQuakes (CoQuake)”.

Time and place: 27 November, 2023, 2:00 pm via Zoom.

## 28 November, 2023

### **Department 2/Topic 3 seminar talk by Dr. Laura Wallace (GEOMAR)**

Title: t.b.a.

Time and place: 28 November, 2023, 10:30 am at GFZ Potsdam, meeting room in A42

The talk will be given in hybrid form. Dr. Wallace started to work at GEOMAR in July 2023.

She will be visiting the GFZ from November 27<sup>th</sup> to Dezember 1<sup>st</sup>. Please contact Frederik Tilmann if you would like to meet her.

## 4-6 December, 2023

### **1<sup>st</sup> International workshop ICDP-Eifel**

Name: EIFEL: Follow the CO<sub>2</sub> – Drilling into an actively degassing intraplate volcano underlain by silicic-carbonatitic intrusion

Place: Physikzentrum Bad Honnef, Germany

<https://www.icdp-online.org/projects/by-continent/europe/eifel-germany/workshops>

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