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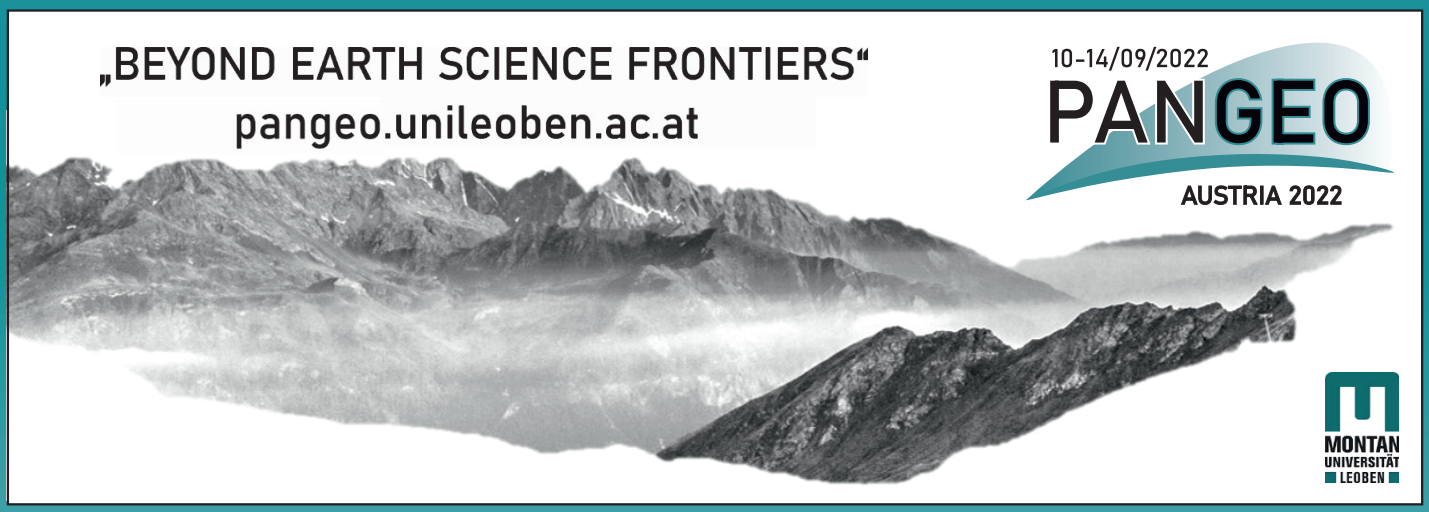

ABSTRACTS and FIELD GUIDES

Geologische Bundesanstalt

10-14/09/2022
PANGEO
AUSTRIA 2022
MONTANUNIVERSITÄT LEOBEN

PANGEO Austria 2022
Abstracts and Field guides

Editoren: Gerd Rantitsch und Johann G. Raith

Montanuniversität Leoben, Department für Angewandte Geowissenschaften und Geophysik

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Contents

Welcome to PANGEO Austria 2022!

The PANGEO Austria 2022 conference is to be held from 10–14 September 2022 at Montanuniversität Leoben. Under the heading “Beyond Earth Sciences Frontiers” this conference provides a platform for presenting actual research carried out at Austrian universities, organisations and companies.

PANGEO Austria has evolved into a forum where scientists from academia can meet with colleagues working in industry and public services. Participation of students presenting results of their Master and PhD projects is strongly encouraged and we hope the conference is not only a place for science transfer and knowledge exchange but also for networking.

The scope of the sessions and contributions give an excellent overview about the wide spectrum of research covered. It ranges from fundamental research in the different disciplines of earth sciences and geophysics to the various fields of applied research with sessions for example on Economic Geology, Geo-Energy, Technical Geology, Hydrogeology and Applied Mineralogy. Two special sessions are dedicated to the geological services in the federal states (Landesgeologie) and to Geology@School; the latter especially adapted for teachers.

Altogether, there are 130 oral and 75 poster presentations. The abstracts published in this volume of Berichte der Geologischen Bundesanstalt document these activities. The scientific programme is accompanied by the social programme and pre- and post-conference excursions. Excursion guidebooks are also published in this issue.

Our sincere thanks go to our sponsors and supporters, to the session convenors, and especially to the staff of the Department of Applied Geosciences and Geophysics who have made it possible to organise this conference. Montanuniversität Leoben is thanked for hosting this conference on its premises, and we thank Geologische Bundesanstalt for publication of this volume.

The organisation team wishes you a successful meeting!

Preface

On behalf of the Austrian Geological Society, I would like to welcome you to PANGEO Austria 2022 at Leoben. PANGEO Austria takes place every two years and is the Austrian showcase of geoscientific research and its applications. Originally planned for 2020, it had to be postponed by two years due to the pandemic. I would like to thank the organizers for all their double efforts and hard work.

PANGEO Austria is quite unique, as it brings together all areas of earth sciences at one conference. Accordingly, the Austrian Geological Society, the Austrian Paleontological Society, the Austrian Mineralogical Society, the Austrian Geophysical Society and the Austrian Association for Hydrogeology are co-organizers of this event. PANGEO has always understood itself as a networking platform, where academia and industry meet and where students, undergraduates and graduates in earth sciences can interact with potential employers. Oral and poster presentations will offer a wide spectrum of high-quality research covering applied, theoretical, and regional themes and will also look “Beyond Earth Science Frontiers”. The opening keynote address by Mike Simmons asks “Who needs geoscientists?” and his answer is a very positive one. Geoscientists will play an essential role in supporting our society during energy transition and transformation. However, we need to give this message to society at large and cast a wide net. PANGEO also offers a Geology@School workshop for teachers. Taking geosciences to school is essential to educate society, and to (re)gain public acceptance and support for our activities.

I wish you all an exciting conference, interesting excursions, lively discussions, and successful networking with real people in a non-virtual environment!

Peter Krois, President of the Austrian Geological Society

Chemostratigraphy of the Cenozoic succession in Azerbaijan: Implications for petroleum systems in the Caspian Basin

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The Cenozoic succession in Azerbaijan includes largely uniform, fine-grained siliciclastic rocks, with a total thickness of a few thousand meters. Age dating of these often carbonate-free sediments proved to be challenging. Hence, the stratigraphy of the Cenozoic succession is still poorly known. The lack of detailed stratigraphic knowledge is frustrating, as the architecture of the Cenozoic succession in Azerbaijan differs significantly from adjacent areas along the margin of the Greater Caucasus (southern Russia, Georgia). Thus, knowledge of the distribution of sedimentary units will also increase the knowledge on the geological evolution of the Eastern Paratethys significantly. A better understanding of the architecture of the Cenozoic succession is also of great importance for hydrocarbon exploration in the South Caspian Basin, as the number of relevant source rock units, their thickness and stratigraphic distribution is still unknown. The main aims of the present contribution are to provide resilient data on the vertical and lateral variation of stratigraphic units in eastern Azerbaijan, together with information on variations of carbonate contents as well as the amount, type and maturity of organic matter. To reach this goal, apparently continuous key profiles representing Lower Eocene to Middle Miocene (Djengi section) and early to uppermost Miocene units (Siyaki section) have been selected using satellite images and accurate descriptions in Soviet-time papers. Each of the sections represents more than 1,000 m of stratigraphy. Additional short profiles (e.g., Shaibler-Gaibler; Yashma, Nasosny, Adzhively) have been selected to study the lateral extent of key horizons. In total, more than 1,700 samples have been investigated for carbonate, sulphur and organic carbon contents, and Rock-Eval parameters. The study results show that potential source rocks are present in three stratigraphic units: (1) Middle Koun Formation (Middle Eocene); (2) Maikop Group (Oligo-/Miocene); (3) paper shales within the Diatom Formation (upper Miocene). The Middle Eocene Middle Koun Formation is about 100 m thick near the coastline of the Caspian Sea and it contains highly oil-prone sediments (max. TOC 15.6 wt.-%; kerogen type II). The Maikop Formation contains relatively high TOC contents (average TOC: ~1.8 wt.-%), but oil prone layers (max. HI: 450 mgHC/gTOC) are rare. The Diatom Formation contains a paper shale unit with very high TOC contents (max.: 21.8 %) and HI values (max.: 770 mgHC/gTOC). The thickness of the paper shale interval may exceed 50 m near the Caspian Sea. In southern Russia and Georgia, the Middle Eocene to Lower Oligocene succession includes marly sediments (Middle Eocene Kuma Formation; Upper Eocene Belaya Glina Formation). In contrast, time-equivalent rocks in Azerbaijan are largely carbonate-free and carbonate-rich layers are restricted to Middle Eocene event beds. This may indicate that the Middle Eocene to lower Oligocene succession in Azerbaijan was deposited in a deeper marine environment.

Controls on biomarker and carbon isotope patterns during the Toarcian anoxic event (Dormettingen section; Swabian Alb)

Ajuaba, Stephen[1]; Sachsenhofer, Reinhard F.[1]; Bechtel, Achim[1]; Galasso, Francesca[2]; Groß, Doris[1]; Misch, David[1]; Schneebeli-Hermann, Elke[2]

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The Toarcian oceanic anoxic event (T-OAE) is associated with a prominent negative carbon isotope excursion (CIE; ~183 million years). About 10-m-thick organic matter-rich sediments accumulated during the T-OAE in the Southwest German Basin (SWGB). Rock–Eval, maceral and biomarker analysis were used to determine variations of environmental conditions across the CIE interval. Carbon isotope records were determined for various n-alkanes, pristane and phytane to contribute to the reconstruction of the paleo-environment and to study the factors controlling molecular $\delta^{13}C$ values. Geochemical redox indicators provide evidence for photic zone anoxia during the Toarcian CIE, which reached its maximum after deposition of the “Unterer Stein” marker horizon. The 2α-methylhopane index suggests enhanced activity of diazotrophic cyanobacteria, which is also supported by nitrogen isotope data. This distinguishes the SWGB from other Toarcian basins with black shale deposition. Oxygen-depleted conditions, albeit with lower intensity continued after the CIE. All investigated organic compounds replicate the negative CIE, but the magnitudes vary considerably. The largest shift is observed for n-C27 (9 ‰) and reflects the combined effect of the global CIE and a major change in organic matter input (termination of terrigenous organic matter input). The shift for short-chain n-alkanes, pristane, and phytane, interpreted to reflect marine biomass, varies between 4.5 and 5.0 ‰. This is the highest value observed so far for any Toarcian section. $\delta^{13}C$ values of pristane and phytane reach a minimum near the base of the CIE interval and increase upsection. Thus, the maximum negative isotope shift predates the strongest basin restriction by about 450 thousand years.

Hydrocarbon potential of Permo-Carboniferous rocks (Weiach, Switzerland)

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In order to quantify the source rock potential of the Permo-Carboniferous succession in the subsurface of the Molasse Basin, the organic matter of coaly and shaly rocks was characterized. In addition, the investigation provides information on the depositional environment. To meet this objective, elemental analysis, Rock-Eval pyrolysis, maceral and palynofacies analysis, biomarker and carbon isotope distributions were performed. 91 samples from the Weiach-1 well representing Carboniferous (Coal Series) and Permian (Lacustrine Series) sediments within the Constance-Frick-Trough were studied. The investigated Carboniferous Coal Series is about 200 m thick and thermally mature. Shaly sediments within the Coal Series contain on average 5.6 wt.-% TOC and gas-prone type III kerogen with an average HI of 130 mg HC/g TOC. Several coal seams occur within the Coal Series, including a main seam with a thickness of ~5 m. The coals have an average TOC of 65 wt.-%. The average HI of all coal samples is 213 mg HC/g TOC and classifies the organic matter as type III kerogen. Hence, the coal seams have a high gas potential. The Lacustrine Series of the Permian succession contains sandstones and shales and is 136 m thick. The average TOC of shale samples is 3.6 wt.-%. Strongly varying HI values (21–480 mg HC/g TOC) show that the organic matter in shales containing different kerogen types resulting from mixing of terrestrial organic matter and different amounts of autochthonous algal material. An approximately 12 m thick shale succession contains on average 4.5 wt.-% TOC. Its organic matter is predominantly oil-prone type II kerogen. Consequently, this interval has a very good petroleum potential. The maturity of the Lacustrine Series (Rr: 0.58–0.76) is within the (early) oil window. Biomarker and isotope data have been determined for the 12-m-thick shale interval. Biomarker indices indicate that oxygen availability decreased during deposition of this interval and that the sources of the organic matter changed. Changes in organic matter type are also supported by palynofacies data and maceral assemblages. $\delta^{13}C$ values of pristane and phytane decrease upwards (-30.33 to -28.47 ‰). This shows a change in the aquatic CO_2 reservoir. Plots of isotope ratios of n-alkanes versus their chain length reflect the different organic matter sources.

Geostatistical approaches to the prediction of sandy reservoir facies based on the analysis of elastic inversion results

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The distinction between oil and gas reservoirs and non-reservoirs is one of the most important problems in petroleum exploration. Prediction of reservoir properties based on seismic data offers benefits for further exploration and development of hydrocarbon-saturated reservoirs. Analytical and numerical mathematical methods can be used to delineate reservoir properties based on elastic inversion results. The application of an integrated approach of joint analysis of petrophysical and seismic parameters allows to predict the optimal distribution of desired reservoir properties. The study was done based on the data from the southwestern Ural Foreland. The studied terrigenous formation consists of medium and fine-grained sandstones, siltstones, mudstones. A small amount of carbonate minerals occurs as pore cement. The studied TK formation belongs to the terrigenous deposits of the Lower Carboniferous and overlies a limestone sequence with interlayers of marls and mudstones. The applied approach to delineate reservoir properties is based on the analysis of elastic parameters of the seismic inversion. In the paper, an integrated approach for the analysis of petrophysical and seismic inverted data is considered, the results of which allow to predict the optimal distribution of the studied reservoir properties. Analytical and numerical solutions for predicting net pay thickness distributions, based on the elastic characteristic discrimination, are proposed. Numerical methods have higher accuracy, but the use of analytical approaches allows the calculations to be simplified and the algorithms to be more flexible for a wider range of programmes, while maintaining high reliability of the results. A 3D seismic cube and 12 wells with petrophysical data were used for this study. Missed P- and S velocities were reconstructed by applying petro-elastic modelling methods. Prestack seismic data were used to define elastic attributes such as P-impedance, S-impedance, Vp/Vs-ratio, Poisson's ratio and porosity. Analytical and numerical geostatistical approaches were used to separate the reservoir sand facies. Cross-plot analysis of PR = f (AI) was used to separate the desirable sand facies of the reservoir part, where PR is Poisson's ratio, AI is P-wave impedance. Initially, the distribution of the area of interest was defined on the cross-plot of PR = f (AI) and referred to as the Field of Initial Events (FIE). Then, in an iterative process, the optimal net pay thickness was calculated until the best correlation with the petrophysical data was established. The finally determined data set was called the Field of Resulting Events (FRE). Both the analytical and numerical approaches demonstrated good correlation with actual net pay thickness – 0.65 and 0.68, respectively. The defined sand reservoir facies were associated with the deltaic-fluvial bars. It was inferred that the fluvial sandy facies prograded from northeast and east to the paleo-shoreline. Tectonic movement of platform blocks in the Early Carboniferous and marine regressions led to the generation of clinoform strata, which are also well traced on the seismic data. Recommendations for further exploration were made and a specific well was proposed.

Prediction of reservoir properties in carbonate and clastic sediments in the South Ural Foreland based on the results of elastic inversion

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Prediction of reservoir properties based on the results of elastic inversion is an important phase of oil and gas fields study. The performance of seismic class prediction is directly related to subsequent success in exploration and further production of the fields. The proposed approaches allow the identification of the saturated part in carbonate and sandy reservoirs. The study area is located in the south of the Ural Foreland. The main exploration targets are in the Middle Devonian to Lower Carboniferous sedimentary succession, which includes massive limestones, dolostones, interlayers of calcareous mudstones, argillaceous-bituminous carbonates, sandstones, coarse-grained siltstones and other clayey-silty-sandy rocks. The oil and gas deposits in the region are associated with both carbonate and terrigenous deposits of Devonian and Carboniferous age. The total thickness of the studied interval is about 2 km. The basement consists of deposits of Riphean-Vendian age, and its surface dips in an easterly and southeasterly direction. The structures of the sedimentary foreland are characterized by a regional subsidence of the strata in a south-southeast direction and a steady flattening of the structures from older to younger ones. The 3D seismic pre-stack and post-stack data as well as petrophysical logs from 4 wells were used to predict the reservoir properties and link the individual seismic lithoclasses. To determine the elastic properties, an AVO seismic inversion transformation was performed and a number of required parameters were calculated: P- and S-acoustic impedances, Poisson`s ratio (PR), Young`s modulus, rock brittleness, Lame parameters (MuRo and LambdaRo), porosity and other attributes. The average correlation of the obtained inverted attributes compared to the petrophysical data can be estimated at 79–84 % over the entire study interval. To separate the reservoir part of the carbonates of D2-L (lower Middle Devonian) and D3-M (middle Upper Devonian) formations, the distinction between density (Den) and porosity (Por) obtained by seismic inversion was applied. Cross-plot analysis of (Den) = f (Por, Br) with brittleness (Br) highlighted helped us to indicate the zone of carbonates development, which is divided into two parts: 1) zone of host carbonate rock; 2) zone of carbonate reservoir. The defined reservoir of the D2-L Formation is characterized by relatively low porosity, high density and high brittleness, which is usually present in fractured reservoirs represented by dolostones. Next, a cross-plot discrimination (Den) = f (PR, Br) was performed for the C1-T (Early Carboniferous) strata. In this reservoir, high density, high porosity and high brittleness are reported. To obtain sandy Lower Devonian (D3-P) reservoirs, cross-plots of MuRo = f (LambdaRo) and PR = f (AI) were used. Low value of MuRo, LambdaRo. PR and AI (P-Impedance) helped to indicate the sand type of the reservoir. Based on the derived information of the reservoir parts of carbonate formations D3-M, C1-T and the sandy formation D3-P, the seismic facies and net pay thickness maps were generated. The determined results were used for further reserve estimations and drilling programs.

Seismic data quality control based on semblance and envelope attribute analysis

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Assessing the quality of seismic data is always an important task for the data obtained after seismic processing. An important preparatory step is the application of suitable criteria and adequate quality control of the processed data. The quality of seismic data is affected by many factors, including geology aspects, seismic acquisition problems, signal processing, and others. To evaluate the quality of the processed post-stack data, the joint behaviour of the envelope (E) and semblance (S) attributes was proposed for consideration. A cross-plot analysis E = f(S) between envelope (E) and semblance (S) was also performed to detect pitfalls and poor-quality records in seismic data. In post-processed seismic data, quality problems may be obscured and not explicitly displayed, and only advanced analysis of wave characteristics can reveal footprints on the record. The developed approach to data quality evaluation was tested on the 3D seismic data of the southern Ural Foreland. The generated envelope (E) and semblance (S) cubes were analyzed for different aspects, with the analysis performed in vertical and horizontal directions. Most importantly, quality was assessed at the level of target horizons, which are located in the lower part of the seismic record. Within the intervals of interest, slices of the envelope and semblance attributes were extracted. A closer look at the obtained slices revealed the existing problems related to the merging of the northern and southern cubes. The border between merged cubes is displayed as footprints. It is also possible to show gaps on traces referring to zero values. The problematic records obtained relate mainly to the southern part of the merged survey and are well highlighted on the semblance attribute slices. The seismic record of the northern part is much less complicated by such pervasive vertical anomalies, except for the marginal zones of minimal folding. For a more detailed identification of the problem areas, a cross-plot analysis E = f(S) between envelope and semlance attributes was performed. With the help of this analysis, three zones of critical values (A, B, C) could be identified. The analysis of the separated zones on the cross-plot E = f(S) helps us to define the areas of the absence and irregularity of the records belonging to the “A” zone, other problem areas of the record corresponding to the “B” zone and the reflections isolated in the “C” zone can be correlated with the regular record. The most representative anomalies of problematic data are identified in the “A” and "B” zones at shallow times of 300–500 ms and are associated with poor recording and other footprints after seismic processing and acquisition. According to the generated time slices E = f(S), existing problems on seismic traces demonstrate their continuation on a smaller scale at times from 500 to 700 ms. The records below 700 ms in the northern sector show much better quality, while there are still recording problems in the southern part; moreover, the pitfalls on the CDPs have a vertical pervasive character. It can be concluded that the seismic survey in the southern sector is plagued with registration problems in many intervals and can obviously be recommended mainly for qualitative estimations and basic structural correlation and is not suitable for quantitative interpretation (seismic inversion, AVO, attributive analysis, etc.).

Pore-pressure and geomechanical parameters prediction based on elastic inversion results

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Predicting pore-pressures and geomechanical properties and developing of recommendations for further drilling are essential problems of geological exploration. It is a major concern to predict abnormal pressures and technological parameters before penetrating the target horizons. In this context, seismic exploration methods are particularly in demand. The latest seismic data processing and post-processing technologies could improve the accuracy of pore-pressure and geomechanical parameter definition. The latest seismic inversion methods also extend the abilities of seismic data to obtain P- and S-impedances and determine elastic constants such as Poisson`s ratio, Young`s modulus, etc. This in turn allows us to define the line of normal compaction much more precisely, calculate the rock and hydrostatic pressures and move on to predicting abnormal geofluid pressures. In the next step, fracture pressures can also be derived from the calculated pore pressures in conjunction with knowledge of Poisson`s ratios. The joint consideration of the determined pore pressure and fracture pressure values enables the prediction of the optimal mud density and windows of drilling schedule. These investigations on the pore pressure and geomechanical properties were carried out in the area of the NY-1 well of the Taimyr Peninsula, which belongs to the northern part of Western Siberia. The region is located in the southwestern part of the Taimyr Peninsula within the Yenisei-Khatanga Trough and consists of a thick sequence of Mesozoic-Cenozoic volcanogenic-terrigenous sediments, in which Upper Permian and Triassic deposits are also present. Petrophysical data from the NY-1 well was attracted for the study. P-wave velocity and two S-wave velocity log records were provided down to 3,694 m depth. Seismic stacking velocities from seismic line 21 were also used. The P- and S velocities were reconstructed in the missing intervals up to 6 km based on petro-elastic modelling. The reconstructed velocities helped to create a low-frequency model for the elastic inversion and to determine P- and S-impedance, Poisson's ratio and other characteristics. Analysis of the inverted P-impedance data at NY-1 well site allowed the normal compaction trend to be established and the overburden and hydrostatic pressures to be defined. Considering the presence of permafrost zone, the normal hydrostatic pressure was derived based on a reduced water density of 0.8 g/cm^3. The first observation of the abnormal pressure was recorded in the Aptian-Albian Yakovlevskaya Formation (1,100–1,200 m), with an anomaly coefficient (AC) of 1.12 to 1.14. The next zone of increased pressure was detected at the level of the Lower Cretaceous Sukhodudinskaya Formation and deeper (interval: 1,660–2,000 m), with corresponding AC of 1.04–1.06. At a depth of 4,900 m, AC reaches 1.23, and below 5,150 m, the pore-pressure AC becomes to 1.45–1.5 and continues to increase with further burial. The determined Poisson's ratio allowed us to determine the fracture pressures. Considering the obtained pore pressure and fracture pressure together in the seismic inverted data enables us to predict the optimal mud density and the drilling windows up to a depth of 6,000 m. The calculations were performed for all CDPs of seismic line 21. The accuracy of predicted mud density at the NY-1 well site was 95–96 %.

The Mallnock tungsten mineralization – Trace element evolution and geochronology (Gurktal Alps, Carinthia/Austria)

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During the late 1980s, systematic alluvial prospecting and field exploration led to discovery of a peculiar type of tungsten mineralization at Mallnock in the Gurktal Alps in Carinthia. The unique feature, which sets Mallnock apart from any other type of tungsten mineralization in the Eastern Alps, is the paragenesis of wolframite (95 mol.-% ferberite) with scheelite. The tungsten occurrence at Mallnock was re-evaluated as a part of the “W Alps” project, which examines the tungsten potential in the Eastern Alps. Scheelite and wolframite were analyzed regarding micro-textures and trace element concentrations using a combination of electron probe microanalysis (EPMA) coupled with cathodoluminescence (CL) and laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS). Tungsten mineralization is restricted to deformed layers of Fe-rich magnesite-dolomite marble within phyllite belonging to the Paleozoic Kaser Complex within the Stolzalpe Nappe of the Drauzug-Gurktal Nappe System. Two different styles of mineralization can be distinguished. At Mallnock-North (MN), ferberite occurs together with scheelite as network fissure fillings in coarse-grained Fe-rich magnesite (15 mol.-% $FeCO_3$, avg. 0.9 wt.-% WO_3). In contrast, at Mallnock-West (MW) scheelite-quartz veinlets are hosted by fine-grained dolomite marbles (avg. 0.5 wt.-% WO_3); i.e., ferberite and ferroan magnesite are missing. Under shortwave UV-light all scheelites show bluish fluorescence, but significant differences in scheelite micro-texture are observed. At MN scheelite clearly replaces ferberite (pseudomorphs) and shows homogeneous CL textures, while at MW scheelite is mostly finely crystallized and occasionally relict cores with primary growth zoning are preserved. Scheelite and ferberite from MN are characterized by a distinct trace element chemistry and rare earth element (REE) patterns. The replacement of ferberite by scheelite is also documented in the trace element composition; e.g., the REE patterns of the two W minerals are comparable. Scheelite from Mallnock has high concentrations of Na, Sr, and U compared to other scheelites from the Eastern Alps, while Mo, Nb, Ta and REEs are rather depleted. The main difference between MN and MW is, that most of the trace elements have a higher concentration at MW where only scheelite is found. Scheelite from Mallnock is particularly rich in U with concentrations of up to 180 µg/g. In situ U-Pb dating of scheelite by LA-ICP-MS yielded Lower Permian and Middle Triassic ages for scheelite from MW and MN, respectively. These scheelite ages are supported by a new Permian U-Pb apatite age of a basaltic trachyandesite dyke farther ENE. The scheelite and apatite ages show that formation of magnesite and tungsten minerals at Mallnock should be interpreted in the context ofthe Permian/Triassic geodynamic evolution of the Alps. Previously, Variscan and/or Eo-Alpine orogenic events were hold responsible for the formation of the wolframite-scheelite mineralization with syn(dia)genetic scheelite as primary metal source.

Forschungsprojekt GeoDrone: AI Workflow

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Beim vorliegenden Projekt GeoDrone handelt es sich um ein von der österreichischen Forschungsförderungsgesellschaft (FFG) gefördertes Forschungsprojekt zwischen dem Lehrstuhl für Subsurface Engineering der Montanuniversität Leoben und der Geosaic GmbH. Ziel des Projektes ist die Auswahl und Anwendung von Artificial Intelligence (AI) Algorithmen bzw. die Neuentwicklung von AI Architekturen zur Lösung von geologischen Fragestellungen durch Nutzung/durch Interpretation klassischer Fotos und 3D Drohnenaufnahmen. Das Projekt gliedert sich in zwei große Bereiche: den geotechnischen bzw. petrophysikalischen Aspekten sowie dem AI Workflow. Diese Präsentation behandelt vorwiegend den AI Workflow. Um möglichst viele geowissenschaftliche Fragestellungen anzusprechen, wurde eine Testumgebung gewählt, die eine Vielzahl von Algorithmen und Architekturen implementieren kann. Hierfür wurde die Google Colab Oberfläche genutzt. Die meisten Bibliotheken für die AI sind somit erreichbar und eine unlimitierte Rechenleistung bei Bedarf abrufbar. Auf dieser Oberfläche wurden Klassifizierungen mithilfe von unüberwachten Algorithmen und gefalteten neuralen Netzwerken (CNN) erstellt. Zusätzlich wurden Segmentierungen mit U-Net und Deep Lab V3+ in Bezug auf geologische Fazies und Struktur durchgeführt. Der Workflow wurde mithilfe von vielen unterschiedlichen AIs und Datenmanagement-Bibliotheken aufgebaut, um bereits eine effiziente Programmierung zu erhalten. Trainings- und Verifikationsdaten wurden teilweise selbst erzeugt und teilweise von vorhandenen Daten übernommen. AI Modelle wurden selbst trainiert und verifiziert, um möglichst viele Interpretationsdaten in die Interpretation einfließen zu lassen. Als erstes Ergebnis steht ein Workflow zur Verfügung, der mithilfe von AI und Drohnenfotos/Kameras von Aufschlüssen, in Kombination mit Experten, geowissenschaftlich auswerten kann. Zur Verbesserung von Vorhersagen werden im Rahmen des Projektes weitere Interpretationen durchgeführt und die Ergebnisse der geomechanischen und petrophysikalischen Auswertungen eingebunden.

Seismic monitoring for deep geothermal projects in Austria

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The last decades showed that many deep geothermal projects around the world (e.g., Basel, St. Gallen, Munich, Pohang) have induced and/or triggered seismicity attributed to them. However, in Austria, many deep geothermal projects have been active for decades and not a single earthquake was associated with them, according to the Austrian Earthquake Catalogue maintained by ZAMG. This study analyses what is necessary in terms of seismic monitoring to locate seismicity sufficiently well to discriminate between natural and associated seismicity at existing and prospective geothermal sites. For these purpose guidelines from neighbouring countries, e.g., Germany and Switzerland are considered. Together with seismological data from Austria, they are used to recommend requirements and identify challenges for successful seismic monitoring.

Hydrochemische Charakterisierung von Blockgletscherquellen mit karbonatgesteinsdominiertem Einzugsgebiet (Beispiel Lantschfeld)

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Im Rahmen einer Masterarbeit wurden das Lantschfeldtal im Salzburger Lungau hydrogeologisch untersucht, wobei der Fokus auf dort befindlichen Blockgletscherquellen lag. Das Gebiet wurde geologisch, geomorphologisch und hydrogeologisch kartiert. An den angetroffenen Quellaustritten wurden die Feldparameter Wassertemperatur und elektrische Leitfähigkeit zu zwei hydrologisch unterschiedlichen Situationen (August und Oktober 2021) gemessen. Des Weiteren wurden Wasserproben der im Einzugsgebiet des Blockgletschers befindlichen Quellen entnommen und auf die Hauptparameter analysiert. Die Geländetermine fanden zu unterschiedlichen Witterungsbedingungen statt. Während nach größeren Niederschlagsmengen im August 12 Quellen im Untersuchungsgebiet angetroffen wurden, wiesen im Oktober, während einer Trockenperiode, nur mehr vier davon aktive Quellschüttungen auf und konnten neuerlich beprobt werden. Die eigentliche Blockgletscherquelle (Lantschfeldquelle) wird im Rahmen des DaFNE Projektes „Blockgletscher als Grundwasserspeicher in alpinen Einzugsgebieten und ihr Einfluss auf übergeordnete Flusssysteme unter dem Aspekt des Klimawandels“ (101561) kontinuierlich beobachtet, so dass hier mehrjährige Datenreihen zur Quellschüttung, Wassertemperatur und elektrischer Leitfähigkeit vorliegen. Die daraus erhaltene Abflussganglinie zeigt ein Abflussverhalten mit Basisabfluss in den Wintermonaten und schnellen Reaktionen auf Niederschlagsereignisse in den Sommermonaten. Zum Vergleich wurde zusätzlich mit der naheliegenden Marbachquelle eine Quelle mit einem verkarsteten Einzugsgebiet beprobt und die hierfür vorhandenen langjährigen hydrographischen Daten in die Untersuchungen einbezogen. Bei den zusätzlich im Einzugsgebiet des Blockgletschers beprobten Quellen handelt es sich überwiegend um oberflächennahe, niedrig mineralisierte Wässer des Ca-HCO_3-Typs. Die Quellwässer zeigen annähernd Kalzitsättigung. Es wurde festgestellt, dass während regenreicher Perioden das zugeführte Wasser primär oberflächennah abfließt. Ein geringer Anteil versickert in den quartären Ablagerungen und dem dolomitisch-dominierten Grundgebirge. Es gibt vereinzelte, perennierende Quellaustritte, die ganzjährig von den Karstaquiferen zehren. Neben der hydrochemischen Signatur, die sich aus der karbonatischen Lithologie des Aquifers ergibt, können vereinzelt auch Bodenlösungsprozesse nachgewiesen werden, welche Spuren von Eisen einbringen. Vor allem das Verhalten der höherliegenden, temporären Quellen wird von den häufig auftretenden Schuttkörpern und glazialen Ablagerungen charakterisiert. Die Blockgletscherquelle ist hydrochemisch mit der Marbachquelle vergleichbar. Zudem lässt sich ein ähnliches Auslaufverhalten des Basisabflusses der beiden Quellen nachweisen. Wird die gesamte Trockenwetterfalllinie verglichen, ergibt sich ein aber deutlich schnelleres Auslaufen der Blockgletscherquelle im Vergleich zur Marbachquelle.

Fluid immiscibility at metamorphic conditions: experimental evidence of fluid inclusions

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The important role of fluids in geological processes is undoubtedly proven by the presence of fluids in abundant rock types, from sedimentary, metamorphic, igneous to extra-terrestrial rock. Metamorphic reactions, melting behaviour, alterations, weathering, ore generation are just a few of those processes that are affected or triggered by the presence of fluid phases. One aspect of fluid research is the knowledge of fluid immiscibility, even at higher temperatures and pressures. Immiscibility of low-density and high-density fluid phases may cause fractionation of economically relevant metals that are dissolved in these fluid phases. Temperature-pressure-composition-density properties of fluid-immiscibility fields are only roughly defined in literature, and lack any thorough thermodynamical modelling. Whereas unary fluid systems (e.g. pure H_2O) have well defined fluid immiscibility conditions (liquid-vapour curve), already binary fluid systems are lacking sufficient experimental data and thermodynamic models. One exception: the most-studied fluid system is H_2O-NaCl, and its fluid immiscibility conditions are well known. An important question that arises: can immiscible fluids be preserved in fluid inclusions? The present work presents a first attempt to investigate synthetic fluid inclusions in quartz that were trapped in the presence of heterogeneous fluids, i.e. immiscible liquid-rich and vapour-rich H_2O-NaCl fluids. The capability of doing so is a prerequisite for a correct interpretation of naturally occurring fluid inclusion assemblages. The experimental conditions (T, P) are selected to obtain equal amounts of 2.41 mass% NaCl vapour-rich fluid (58.51 cm^3/mol) and 41.40 mass% NaCl liquid-rich fluid (29.34 cm^3/mol), that is obtained from on original 30.07 mass% NaCl solution (loading conditions). Both fluids can be trapped simultaneously in small cracks within quartz crystal. The first results illustrate that these fluids are not preserved within newly formed synthetic fluid inclusions. Inclusions with relatively large vapour bubbles contain the original 30 mass% NaCl solution, which was trapped before the immiscibility field was reached in the experiment. The liquid-rich inclusions reveal properties that resulted from the mechanically mixing of little salt crystals with the liquid phase. In conclusion, narrow cracks in quartz crystal may heal instantaneously, within one hour in an experimental heating run from room temperature to 600 ˚C. At the final experimental conditions only traces of the liquid-rich fluid are trapped in the remaining cracks, which may be coated with small NaCl crystals, that formed during the unmixing process. The vapour-rich fluid is not trapped, due to its wetting properties, which prevent entering of small bubbles into narrow cracks. These cracks are completely wetted with the liquid-rich phase. There is no reason to assume that the crack healing process in the experiment is different from natural processes. These results put some restrictions on recognizing heterogeneous entrapment processes in natural rock.

A novel quantitative approach to sedimentary petrography: Next-generation SEM-EDS-based automated mineral mapping

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The dynamic evolution of the Earth`s surface systems is recorded in terrestrial and marine sedimentary archives. However, post-depositional processes, such as diagenesis, metamorphism and hydrothermal overprinting, can alter the primary sedimentary constituents, which limits our understanding of the identity, origin, composition and genesis of individual grains. A fundamental limitation of previous paleo-environmental and paleo-depositional reconstruction studies is their reliance on bulk mineralogical and geochemical techniques, which are unable to differentiate sedimentary constituents of various origin, such as detrital (physical vs chemical weathering) and authigenic (syn-depositional vs burial diagenetic) grains. We demonstrate that next-generation Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEMEDS) analysis can now reveal the petrological context of each grain. This advancement comes as a result of recent technological improvements, including fast spectral acquisition times and quantitative deconvolution of mixed-phase spectra to produce ‘mixels’, which greatly improves mineral identification in previously troublesome fine-grained lithologies and at mineral/grain boundaries. We show that SEM-EDS-based mineral mapping can provide fully quantitative mineralogical data comparable to conventional X-ray diffraction analyses of powdered bulk rocks ($R2 > 0.95$, $n = 268$), if (i) strict error minimization spectral matching approaches are used, (ii) region of interest (ROI) placement is correct (i.e., vertical segments perpendicular to bedding especially in laminated fine-grained rocks) and (iii) the volume of the imaged area is properly defined (~1 mm^2). We examine novel applications for SEM-EDS-based mineral mapping and quantification in the Earth Sciences via selected case studies, featuring 1) a precise differentiation of detrital vs authigenic clays in paleoenvironmental and diagenetic contexts and 2) the utility to identify and characterize target grains or mineral fractions prior to geochemical (sequential mineral leaching protocols) or in-situ geochronological (Rb-Sr dating via LA-ICP-MS/MS) analysis of clayey sediments.

High resolution seismic surveying of the Cheb Basin

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In this study we present first results from several shallow high-resolution reflection-seismic profiles from the Cheb Basin (Czech Republic) collected in the years 2014–2020. The Cheb Basin is a small intracontinental basin, located in the Bohemian Massif, at the Western end of the Cenozoic Eger Rift, which is the target of the ongoing International Continental Scientific Drilling Program (ICDP) “Drilling the Eger Rift”. Our surveys aim to investigate the up to 350-m-thick Miocene and Quaternary basin sediments and the bedrock of Variscan units and post-Variscan granites. We collected four datasets in total, each with a 480-m-long split-spread of single geophones at 2 m spacing. A 3-km-long profile near Hartoušov was acquired with a 10-m-spaced 240-kg-weightdrop source, with SISSY (gun) shots interspersed where the terrain was not accessible to the weight-drop. The other three profiles of 2 km, 0.8 km and 1 km length, respectively, were shot with a 4-gauge buffalo gun at a 20 m spacing. Additionally, we performed some remote shots at up to 1 km distance to record the refraction from the bedrock. In a first processing step we devised an automated method to optimize an inverse filter that removes a second impact from the weight-drop source. We will also compare the type of the source on the quality of the data and signal characteristics. At the current processing stage, we focus on the construction of high-resolution velocity models of the near surface for the computation of refraction statics.

Quantifying fracture intensity (P21 values) in drill cores of the Hauptdolomit Formation using digital image analysis (ImageJ)

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As part of the “Geotief EXPLORE 3D” project, a research borehole was drilled in rocks of the Hauptdolomit Formation in an exposure in equivalent position to reservoir rocks in the subcrop of the Vienna Basin. The dolostones of the Hauptdolomit Formation are considered as potential exploration targets for deep geothermal energy. The Hauptdolomit Formation is a typical fractured and faulted reservoir in which porosity and permeability are supported by fractures with areas and lengths varying over several orders of magnitude. In support of porosity and permeability analysis from logs and drill hole tests, computed tomography (CT) scans of drill core were taken and analyzed. The aim of the digital image analysis was the computer-aided determination of the fracture intensity (P21 values in m/m²) in the drill cores, with the P21 value being defined as the length of the fracture traces per unit area. The P21 values are compared to porosity data. The computer-assisted P21 analysis method can use both microscopic images of scanned thin section images and images from CT scans. The analysis was performed with a software freely available on the Internet, ImageJ (Fiji, version v1.53s). The images were filtered using a segmentation plugin (WEKA segmentation) so that a distinction can be made between fracture trace and matrix. WEKA segmentation is a Fiji plugin that combines a collection of machine learning algorithms with a set of selected image features to create pixel-based segmentations. WEKA (Waikato Environment for Knowledge Analysis) includes a collection of visualization tools for data analysis and graphical user interfaces for easy access to these functions. The images were then converted into 8-bit grayscale images for further processing and then into binary images. The conversion of a grayscale image into a binary image, where black represents the region of interest and white represents the matrix, was done by defining a global threshold within the grayscale histogram with 255 levels. In a last step, the areas to be examined were converted into a line display (skeleton), in which all the fractures determined by the program are displayed as lines in order to subsequently determine the P21 value. The results of the image analysis show a good correlation of the P21 values with porosity data determined from logs. P21 values from a total of 32 CT scans show a correlation factor of about 82 % with the porosity data from the respective depth interval. The image analyzes carried out thus show a very good correlation between fracture intensity and porosity.

Phi_K Hautpdolomit: tiefenabhängige Porositäts- und Permeabilitätswerte eines bedeutenden Reservoirs für Kohlenwasserstoff- und geothermische Energiegewinnung

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Die Hauptdolomit-Formation stellt eines der wichtigsten Explorationsziele für tiefe Geothermie im Untergrund des Wiener Beckens dar. Die Reservoireigenschaften werden im Wesentlichen von Bruch- und Kluftnetzwerken bestimmt, die ein sehr breites Spektrum von Skalen abdecken und von Mikroklüften im Millimeter Maßstab bis hin zu Klüften in seismischem Maßstab reichen. Daten aus früheren Analogstudien in der Hauptdolomit-Formation sowie Studien aus Bohrloch- und Produktionsdaten zeigen deutlich, dass tektonisch bedingt stark zerbrochene Zonen äußerst wichtig für die räumliche Verteilung der Permeabilität in den Gesteinsmassen sind. Die vorliegende Studie präsentiert Daten der durch Mikro- und Makrobrüche bereitgestellten Porosität und Permeabilität im Hauptdolomit. Die Studie wurde im Rahmen des Projekts „Geotief EXPLORE 3D“ durchgeführt und umfasst Aufschlussproben der Hauptdolomit-Formation aus insgesamt 6 Aufschlüssen im Frankenfels-Lunz Deckensystem und der Göller Decke der Kalkalpen südwestlich von Wien, die als Äquivalente der Speichergesteine im Untergrund des Wiener Beckens gelten. Der Datensatz enthält sowohl geklüftete Gesteine als auch Störungsgesteine (Brekzien und Kataklasite). Um Unterschiede in der Kluftdichte abzubilden, sind Porositäts- und Permeabilitätsdaten entsprechend der Kluftdichteklasse aufgeschlüsselt. Die effektive Porosität (%) wurden nach der Klassifizierung der Kluftdichte durch Tauchwägung nach ÖNORM EN 1936 an größeren Probenkörpern bestimmt. Mit einem vollautomatisierten Gasporosimeter/Permeameter wurden an Plugs Gasporosität (%) und Klinkenberg-Permeabilität GAS (mD) bei Umlagerungsdrücken zwischen 400 psi und 6.500 psi gemessen, um die Überlagerung bis etwa 3.000 m Tiefe zu simulieren. Messungen nach ÖNORM EN 1936 ergaben effektiven Porositätswerte von 1,09 % für mäßig geklüftete, 1,80 % für stark geklüftete und 3,75 % für sehr stark geklüftete Probenkörper. Unter den Störungsgesteinen weisen Brekzien durchschnittlich 3,65 % und Kataklasite 4,64 % Porosität auf. Gasporositäten liegen zwischen 0,8 % und 10 %, im Durchschnitt 4,09 ± 2,03 %. Die Gasporositätswerte zeigen eine gute Korrelation mit Porositätswerten aus der Tauchwägung und eine signifikante Zunahme mit steigender Kluftdichte. Permeabilitätswerte (Klinkenberg-Permeabilität GAS in mD) für Plugs mit 1,5‘‘ (38,1 mm) Durchmesser und 26–70 mm Länge bei 400 psi Umlagerungsdruck, liegen zwischen 5E-05 mD (Min.) und 30,5 mD (Max.). Der Datensatz zeigt eine grundsätzliche leichte Zunahme der Permeabilität mit steigender Kluftdichte bei hoher Streuung der Permabilitätswerte über alle Kluftdichteklassen hinweg. Störungsgesteine haben eine geringe Permeabilität von < 0,1 mD. Die an Plugs bei 400 psi Umlagerungsdruck gemessenen Porositäts- und Permeabilitätswerte zeigen eine positive exponentielle Korrelation mit sehr hoher Streuung. Mit zunehmendem Umlagerungsdruck zeigen Porosität und Permeabilität eine signifikante Abnahme. Porositätswerte zeigen eine Abnahme um etwa 22 %, Permeabilitätswerte um etwa 68 %. Die vorliegenden Daten wurden im Rahmen des Projekts „Geotief EXPLORE 3D“ auch in Reservoirmodelle eingebracht und bilden so einen Beitrag zur Hochskalierung von Porositäts- und Permeabilitätseigenschaften der Hauptdolomit-Formation.

Growth of brucite on portlandite crystal surfaces

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Brucite ($Mg(OH)_2$) and portlandite ($Ca(OH)_2$) are both hydroxide bearing minerals. But while portlandite is a main mineral phase in the cement matrix of concrete, brucite forms as a degradation product of concrete exposed to magnesium bearing solutions. Similar to other precipitates preferentially formed on the surface of concrete components, brucite may act as a protective barrier preventing or delaying the progress of concrete degradation. As portlandite has a significantly higher solubility compared to that of brucite, the effect of brucite formation as protective layer on portlandite is worth to be investigated. However, the corresponding reaction kinetics and mechanisms have not been fully explored. The present study gives insight into the potential protective effect that brucite may provide to prevent the mineral portlandite from dissolution. For this study, single crystals of portlandite were synthesized and exposed to Mg^{2+}-containing solutions for 72 h, where the impact of the following parameters was investigated: (i) Mg^{2+} ion sourced from chloride, sulfate and nitrate salt, (ii) Mg^{2+} concentrations of the initial reactive solution and (iii) mass ratio of exposed crystal surface to solution volume. Therefore, portlandite crystals were partly coated with nail polish forcing the brucite growth on a single hexagonal surface. The crystals and solutions were analyzed with FTIR, optical microscope, SEM, EPMA and IC, pH-sensor. Thermodynamic modelling was performed using PHREEQC. The results show brucite layers to be formed directly on or close to the portlandite crystal surface in all experiments. The factors influencing brucite formation were closely linked to the evolution of the calcium concentration of the reactive solution. Thus, aqueous Ca^{2+} content could be used as an indicator of the ongoing reaction process. The reactive solutions with chloride- and nitrate-based Mg^{2+} at high concentration levels provided optimum conditions for brucite formation to inhibit portlandite dissolution, where no further mineral was formed throughout the experimental runs. The presence of sulfate ions led to the formation of gypsum ($CaSO_4.2H_2O$) once a threshold concentration of sulfate and calcium in the reactive solution was reached. In those cases, a brucite layer is formed first and subsequently gypsum filled the space left open by the dissolution of portlandite. In a progressing stage gypsum created cracks in the brucite layer and accordingly lowered the protection against portlandite dissolution. Thus, the availability of the sulfate ions in reactive solution plays an important role for the concentration of aqueous Ca^{2+}. A crucial factor for brucite formation throughout all experimental runs was the initial Mg^{2+} concentration, which directly influenced the time-resolved evolution of the pH. The pH in turn determined the morphology of the brucite crystals, which was decisive for the effectiveness of protection against further dissolution of the portlandite crystal: higher Mg^{2+} concentrations are associated with lower pH and result in brucite layers with smaller, more densely packed crystals offering noticeably better protection against portlandite dissolution compared to the appeared thicker brucite layers consisting of larger crystals with a higher layer permeability. A conceptual model for the different interacting parameters was developed where the stages of distinct reaction kinetics and mechanisms are discussed and assessed.

Magnesite deposits in the Eastern Alps – integrative approaches

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Austria is an important producer of magnesite which is used to a large extent in the refractory industry. In 2020, 816.370 t of magnesite were produced. Sparry magnesite deposits are the economically most important type in Austria. In order to secure the supply of magnesite and minimize dependence on exports from China, it is important that primary mining is also actively pursued in the future. Therefore, in addition to resource efficiency and recycling, raw material exploration will continue to play an important role. Successful exploration in turn requires knowledge of the national raw material potential as well as the deposit-forming processes, as only on this basis a correct exploration model can be developed. Magnesite deposits occur in different Austroalpine geological-tectonic units and their genesis has been debated for decades. More recently epigenetic metasomatic-hydrothermal models have been revived although in the past also syngenetic models were discussed. This MRI (Mineral Rohstoff Initiative) project – a cooperative project between Geologische Bundesanstalt, Montanuniversität Leoben, Technische Universität Graz and RHI Magnesita – is intended to provide clarification about application-oriented and basic research-oriented questions. A main objective of applied research aspects is the three-dimensional/vertical distribution of minerals (silicate phases etc.) and their compositional variation within the Breitenau deposit. Here, the main question is whether there exists a facies-controlled variation in the chemistry/mineralogy with increasing depth and whether this may influence the quality of the raw material. Various methods will be used to tackle open scientific questions. Fluid Inclusion studies can provide information on the pressure-temperature conditions of magnesite formation and the chemical composition of the fluids. They have only been carried out to limited extent on magnesite deposits in the Eastern Alps and are to be accelerated in this project. Sm-Nd dating of magnesite from two deposits (Breitenau, Hohentauern) located in different geological units, yielded Early Triassic and Late Carboniferous/ Early Permian ages, respectively. The differing ages indicate more than one event of magnesite formation in the Eastern Alps. Other important deposits like Hochfilzen are not dated yet. Recently, new isotope chemical methods became available in addition to classical stable isotope methods. Magnesium isotope composition of magnesite had been analysed in a previous one-year MRI project. The analyses show some variation in the limited magnesite data set and the reasons for the observed fractionation have to be further explored. Clumped isotopes have the potential to obtain formation temperatures of carbonate minerals. In combination with mineralogical-petrological methods (e.g., carbonaceous matter Raman geothermometry) and FI studies it should be possible to better constrain the conditions of ore formation. Together with additional age data these data hopefully will allow establishing a correct genetic model. When integrated with the modern geodynamic-tectonic concepts of the Eastern Alps this provides the basis for future exploration for magnesite.

MASW imaging from shallow seismic reflection data

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In the last two decades, MASW (Multi-Channel Acquisition of Surface Waves) has become a staple for shallow seismic characterization in form of shear-wave velocity models. However, in its classical form the MASW method is restricted to layered media with little lateral variation and relies on dedicated equipment and data acquisition parameters such as land streamers and low-frequency geophones with small receiver spacing. Nonetheless, P-wave near-surface reflection and high-density refraction data often show significant surface wave energy which largely remains unused since the acquisition geometry and therefore the data are considered unfit for conventional MASW imaging. Furthermore, significant topographic variation and small scale subsurface inhomogeneities challenge most classical dispersion imaging and inversion algorithms. We show how this non-optimum but still useful data can be turned into robust subsurface shear-wave velocity models which in turn supplement the P-wave models and their interpretation. Our suggested approach aims at minimizing manual interaction and effort for the processor. The workflow includes advanced sorting and stacking techniques, improved dispersion analysis for low-quality data, and a laterally constrained joint inversion of all dispersion curves into one final 2D or 3D model. This final result, obtained at almost no additional costs, can be a valuable by-product for any conventional P-wave field campaign. We also argue that the method provides an alternative to deriving shear-wave velocity models from S-body wave travel time picks, which usually can only be estimated with considerable uncertainty in shallow P-wave data. The practicability of the approach is demonstrated with several examples from different geologic environments and application scenarios.

What's old is new again: can old, unpreserved core be used for modern seal rock characterisation?

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With the demands for decarbonisation due to anthropogenic climate change, earth scientists are looking to the subsurface for its storage potential for carbon capture and storage (CCS) and underground hydrogen storage (UHS). Depleted oil and gas reservoirs as well as deep saline aquifers have been proposed as potential storage sites for CCS and UHS. Important to the understanding of potential storage sites is the long-term integrity of the seal overlying the proposed reservoir units. In this study, we aim to understand the physical properties of old shale core, stored under atmospheric conditions in a core shed since the 1970s, compared to a similar, recently acquired core that has been preserved to modern standards. This study presents the results of a suite of experiments to characterise the physical properties on old, unpreserved cores and new, preserved cores taken from geological units of similar age and depth in order to determine the difference in properties between the old and new samples. Our aim is to determine the suitability of older cores for studies examining the performance of shales with respect to secondary storage. The new, preserved core has water content approaching in-situ, which is therefore higher than in the nearly 50-year old unpreserved core. Porosity was measured by helium pycnometry, mercury intrusion porosimetry, and broad ion beam scanning electron microscopy (BIB-SEM). Although there is variation of the porosity measurements between the methods, there is relatively good agreement within each method for the old core vs the new core. The differences of the average porosity of the new samples from the average porosity of the old samples is 3.8 for helium pycnometry, 3.2 for mercury intrusion, and 3.0 for BIB-SEM. The preserved core, therefore, has slightly higher porosity than the old, unpreserved core. The lower porosity in the old core is interpreted as the result of pore closure due to drying and shrinkage of the samples at the scale measured by the above methods. Minor to moderate cracking is observed in the SEM images of the unpreserved core samples, which supports some volumetric changes due to drying of the unpreserved samples. Multistage triaxial compression testing of the samples was undertaken to determine their strength parameters, including cohesion, friction angle and unconfined compressive strength (UCS). The old, unpreserved samples show higher strength parameters than the preserved samples. This is a result of lower water content and slightly lower porosity. Furthermore, the UCS values for the unpreserved core do not correlate well with Poisson's ratio and Young's modulus, whereas they do for the preserved core. This indicates that the strength testing results for the unpreserved core may not be reliable. The results of this study show that there is variation in the porosity results between the different methods, and that preserved core has slightly higher porosity than the unpreserved core. Although the preserved core does have higher porosity, the difference is relatively small. Therefore, unpreserved core that is otherwise in good condition can be considered appropriate for porosity characterisation. Conversely, there are significant differences in strength parameters between old and new core, suggesting that unpreserved core is not suitable for such testing methods.

Calcite dissolution in claystones treated with brine and hydrogen: implications for underground hydrogen storage caprock integrity

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Underground hydrogen storage (UHS) in depleted oil and gas reservoirs or deep saline aquifers raises questions regarding changes to potential caprocks/seals that come into long-term contact with hydrogen. In this study we present the first results from a series of hydrogen treatments applied to caprock-analog claystones collected from quarries in Germany. One of four treatment options was applied to each individual sample: (i) untreated (reference), (ii) hydrogen gas treated (dry-H_2), (iii) NaCl brine treated (brine), and (iv) NaCl brine and hydrogen treated (brine-H_2). Although the dry-H_2 treatment option is unlikely to be reflective of in-situ UHS conditions, due to the likelihood of some fine-grained sedimentary rocks to swell and slake when saturated, the dry treatment option is included here to determine if any meaningful results may be obtained by the experimentally easier dry-H_2 treatment option. Following 30-day static treatments the samples were analysed via broad ion beam-scanning electron microscopy (BIB-SEM). From the SEM images, significant dissolution of calcite fossil fragments was observed in samples that were treated with a combination of hydrogen and 10 wt.-% NaCl brine. No significant textural changes were observed in samples that were treated with hydrogen alone. The initial results indicate that there is potential for alteration of calcite within caprocks of hydrogen storage systems, which could have consequences for long-term storage. Furthermore, the lack of dissolution observed with the dry hydrogen treatment indicates that, although experimentally easier, this treatment option does not result in significant dissolution. These results also highlight the need for further, robust testing of seals and caprocks in potential UHS systems.

Mineral chemical evolution of metapelites along the prograde Eoalpine metamorphic field gradient in the southern Ötztal Complex (Vinschgau, S-Tyrol, Italy)

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The currently mapped sheet Schlanders (CARG 012) offers the chance to carefully investigate the Austroalpine units in the Vinschgau and their tectonic contacts and to implement them into a tectonic model based on new petrological, geochronological and structural data. The Austroalpine nappe stack in the investigated area, located in the Vinschgau area (Southern Tyrol), comprises from bottom to top the Campo-Ortler (COC), the Texel (TC), the Ötztal (ÖC) Complexes and the Matsch (M) Nappe. These Austroalpine basement units in the northern flank of the Vinschgau valley (e.g. Matsch Nappe, Ötztal Complex) show a clear polymetamorphic evolution history which can be well reconstructed using the spatial distribution of the alumosilicates, the chloritoid-isograd and the observation of chemical zoning patterns in garnets, which depending on the geographical position and the geological setting, exhibit single-phase, two-phase or even three-phase compositions. Geothermobarometry yielded a strong increase in eo-Alpine temperature conditions of 500 °C and 0.8 GPa to 650 °C and 1–1.2 GPa. The following mineralogical and chemical changes occur in the metapelites of the Matsch Nappe: Chloritoid isograd: Staurolite breaks down to form either chlorite or chloritoid. West of the isograde the reaction 10fst + 82an + 94H_2O = 8daph + 82ma + 51q can be observed. East of the isograde the reaction 2fst + 10ab + 14H_2O = 10pa + 8fctd + 7q can be observed. With respect to the Ca-phases a change in margarite (west) to grossular-bearing garnets (east) occurs. Garnet: Especially in the Matsch Unit, a clear spatial distribution of garnet zoning can be observed: in the west, the garnets show only a Variscan composition (Grt I) with a very small Ca-rich Eoalpine growth rim (Grt II). Further to the east, the proportion of this Grt II rim increases until only a residue of the older core Grt I remains. The garnets surprisingly show a third very low calcium generation (Grt Ib), which occurs between the Variscan core Grt I and the Eoalpine rim Grt II. Since this Grt Ib distribution spatially correlates well with the occurrence of leucocratic othogneisses and pegmatites, a Permian age is supposed. Ilmenite: The chemical composition of ilmenite also changes in accordance with increasing Grt II growth. Ilmenites west of the isograd are Mn-rich (2–3 wt.-% MnO) and east of the isograd MnO decreases to 0.5–1.5 wt-.%. Plagioclase: Anorthite contents also change with increasing metamorphic conditions from 2 mol.-% in the west to 31 mol.-% in the east. Aluminum silicates: All three aluminum silicates also occur in the mapped area. Andalusite and sillimanite show a clear geographical distribution, where andalusite occurs in the western part and sillimanite occurs in the eastern part of the Matsch Nappe. Relict kyanite occurs only isolated in the western part of the region and is thought to represent a relict from the Variscan metamorphic event. The geographical distribution of the aluminum silicates indicates a change of Permian P-T conditions from west towards east, which also correlates well with the occurrence of leucocratic orthogneisses. Tourmaline: Tourmalines west of the chloritoid isograd show a complex chemical zoning pattern with 3–5 zones, whereas east of the isograde only 2–3 zones occur. The Ca-content of tourmaline is indicator of increasing metamorphic conditions and correlates well with an increase from the west (0.6 wt.-% CaO) to the east (0.9 wt.-% CaO).

More than meets the eye: investigating critical elements in sulfides from different ore deposit types

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Mineral geochemistry has multiple applications for understanding the geological processes that formed the mineral. Plenty of research has been done on trace element compositions of sulfides from different ore deposit types to find a deposit-type characteristic geochemistry. Besides the characterization applications of trace element analyses, it is also important to investigate the presence and distribution of 'critical elements' in ore deposits. Critical elements are elements that have a growing economic importance and high supply risk. The European Commission publishes a list of critical elements, including Co, Ga, Ge, In, Sb, Bi and platinum group elements, which commonly occur in sulfide minerals in varying concentrations. Many of these elements are used in green technology and new sources of these elements are required to fulfill our goals of a sustainable green future. Most of these critical elements rarely form distinct minerals but are rather hosted in trace to minor amounts within other minerals and are thus commonly mined as by-products from other targeted resources. We apply an array of geochemical methods to study the distribution of critical elements in sulfides, with a major focus on LA-ICP-MS trace element analyses. Laser ablation (LA)-ICP-MS enables in situ analyses of small (30–100 µm) and precise parts of the sulfide minerals. As most ore deposits form through multiple phases of mineralization, sulfides commonly show zonation and generational differences in geochemistry. Trace element mapping by LA-ICP-MS and EMPA are both powerful tools for element distribution visualization. Our research indicates that many different ore deposit types show potential for being sources for critical elements, as by-products from mining other base metals. Sphalerite from European Alpine-type carbonate-hosted Pb-Zn and many MVT deposits contains significant concentrations of Ga and/or Ge. The sphalerite from these carbonate-hosted deposits commonly occurs with banded textures, indicating multiple generations, and LA-ICP-MS data shows a wide variation in trace element concentrations. The Polish Kupferschiefer hosts djurleite with elevated Re concentrations and chalcopyrite from later stages of mineralization with higher concentrations of Ga. The Dolostone Ore Formation mineralization in Namibia, a sediment-hosted Cu-Co mineralization, does not only contain Co-sulfides but both pyrite and sphalerite contain high concentrations of Co. Although pyrite contains abundant Co-bearing micro-inclusions, sphalerite seems to host lattice-bound Co. Evident from all these studies is that sulfide trace element composition varies between the different generations of ore formation at these different deposits. This is an important aspect to keep in mind when exploring for critical elements and designing metallurgical test work programs. In addition, we are also looking into the evaluation of old mine tailings as a possible source of critical elements as these elements used to have no value and were therefore disregarded during processing. Being able to re-process old mine tailings could provide a sustainable source of critical elements.

Source time functions and interference from blast arrays

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We present a method to predict realistic source time functions for mine blasts that we developed for one of Europe's largest iron ore mines, Mt Erzberg, Austria, where we repeatedly monitored production blasts with a large array of seismic sensors. That allows us to simulate not only resonance modes, but also waveforms. We verify our predictions with observations from 39 electronically ignited blast sequences. Our target function to optimize the model is the normalized crosscorrelation coeffcient of observed and synthetic waveforms. It varies widely, often from 0.1–0.8, for the same blast array, suggesting that ground motion is far more predictable at some sensor locations than at others. The dense array and an almost full azimuthal coverage also allow us to verify the predicted Doppler shift that arises from the small spatial delays between the blast holes. The good match of our predictions suggests that our model could be used for more advanced predictions of the peak ground velocity, which is essential to designing charge weight distributions in modern mining operations.

The AdriaArray project

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The AdriaArray is a new European-scale initiative to study the subsurface under our continent, following up on the successful AlpArray project, which has created many new insights about the Alpine region. AdriaArray will (again) have a massive seismological network as its core, federating researchers from 27 European countries, and more than 1,300 seismological stations. The spatial focus of the new AdriaArray will extend from the Alpine region to Southeastern Europe, to Poland, Ukraine and Greece – the region on and around the Adriatic plate. Goals are to better understand the subsurface at crustal, lithospheric and mantle depths, its deformation, seismicity, the major faults, the state of stress of the region, the geometry and nature of mantle slabs, and the geological evolution – and how the transitions between topographic and geological domains of the Alps, Pannonian Basin, Carpathians, Dinarides, Eastern European Craton, Balkans, and the Aegean occur. In this presentation we will revisit some of the major results from the AlpArray project, and present the AdriaArray consortium, and some of its scientific plans.

A novel upscaling workflow of multi-phase flow properties for water-, and mixed-wet reservoirs – applications for conventional hydrocarbon field developments and low-carbon business

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Within OMV's digital transformation program, we are combining the latest software developments in digital rock simulation (DRS) and special core analysis (SCAL) simulation, with SCAL data mining and log-based upscaling to provide reservoir engineers swiftly with multi-phase flow characteristics to predict reservoir performances. Unlike classical investments in time-consuming and cost-intensive laboratory workflows, flow properties are estimated by a petrophysical data-model sourced from a rock-fluid database, supported with digital rock simulation, and where required, SCAL measurements. DRS- and database derived relative permeabilities, including associated uncertainties, are key input parameters to impact decision quality in field developments and can substantially accelerate reservoir simulation workflows. Current estimates expect that relative permeabilities can be obtained significantly faster from the new, combined workflow of DRS, SCAL database and log-based data predictions, compared to running individual special core analysis programs in labs for a field. The agile managed project has entered the execute phase in April 2021. It is planned for 3–5 years, delivering minimal viable products (MVPs) in yearly super-sprints, with increasing scope of complexity. The project scope covers clastic and carbonate reservoirs with varying multi-phase flow properties. Gas and oil-bearing reservoirs are included, with rock wettability ranging from water-wet to oil-wet. Moreover, for the mid-term scope, multi-phase flow properties for renewables / carbon capture storage are also considered. In 2021, we worked with our project partners on key wells from Norwegian and Austrian fields, and results from the MVP 2021 (water-wet reservoirs). Due to the positive outcome of the proof of concept, multiple pilot projects are currently scheduled with the business units to apply the developed upscaling concept. Results of the Pilot projects have been already reviewed, incorporated in the dynamic modelling, together with the field reservoir engineers, and will be shared herein. Further technical development in all the work streams is ongoing. In DRS, the latest developments on dynamic pore morphological simulations will be evaluated for mixed-wet reservoirs. In parallel, advances in digital geochemistry modelling and applications for low carbon business will be evaluated. In the SCAL stream, the rock-fluid database is continuously growing, and new experimental data is constantly being uploaded into the database. Therefore, the modelling of fluid flow properties and their uncertainties will be continuously improved. Besides ongoing updates in the DRS and SCAL streams, the inhouse development on the probabilistic log interpretation application will be also continued. By end of 2022, developed MVPs allow to track, monitor (over time), and predict (probabilistic, data-based) multi-phase flow, to enable better decisions for field developments and optionality for more favorable business cases in conventional hydrocarbon field developments, low-carbon business, or enhanced hydrocarbon recovery.

Passive seismic methods for geothermal exploration: A case study from the Jinqu Basin (China)

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Geothermal resources are considered as underutilized contributors to diversification of the growing energy needs worldwide. Like several other nations, China embarked on a program to explore potential geothermal reservoirs. We present a case study from the Jinqu Basin in southeastern China where ambient seismic noise tomography was applied to investigate the geologic structure in regard to its probability for hosting temperate ground water in large depths. The Jinqu Basin is located ca. 300 km southwest of Shanghai and comprises sandstones and conglomerates on top of volcanic units. Heatflow is around 75–80 mW/m², and temperate surface water is characteristic for the region. A passive seismic survey was conducted to identify potential zones with increased fracture density. The passive method allows to cover large areas in short time at minimal costs, while it provides low-resolution velocity models only. Nonetheless, in the initial stage of exploration low-resolution and spatially extended 3D models are required to plan detailed reflection seismic acquisition and drilling locations in later phases. The passive seismic survey comprised 192 recorders, which were deployed for 5 days in a 20 km² wide area. Continuous recording of ambient seismic energy (e.g., traffic noise, cultural noise) allowed for the application of interferometric analysis and tomographic inversion. The main result is a 3D shear-wave velocity model, which extends to a depth of ca. 2 km. The model shows a low-velocity anomaly which correlates with low electrical resistivity from a previous 2D magneto-telluric campaign. This anomaly is interpreted for a zone of increased fracture density and will be considered for future active seismic acquisition. It is concluded that passive seismic methods are useful for large scale geologic exploration in the context of geothermal reservoirs because of their low costs and short acquisition time. The obtained shear-wave velocities are sensitive to fracture density, which is an important property of potential reservoirs. Depending on the type and availability of ambient seismic noise, the method can be scaled from a depth of few tens of meters to several kilometers.

Passive seismic imaging of bedrock depth and sediment fill of an alpine valley in the Colorado Plateau (US)

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Unaweep Canyon is a large gorge that bisects Colorado`s Uncompahgre Plateau and is globally unique, named for the odd occurrence of a divide in its midst, from which two creeks flow in opposite directions. The 50 km long canyon incises through Mesozoic strata into Precambrian basement but hosts a thick sediment fill of Pleistocene and possibly older age. The shape of the canyon and geologic observations led to the hypothesis that the valley was glacially overdeepened in the late Paleozoic, which would challenge current climate models of that period. Previous geophysical and drilling campaigns provided bedrock depth estimates of more than 350 m along cross-sections. To investigate the longitudinal structure of the bedrock and the sediment fill, we deployed 120 passive seismic recorders along a 4.5 km long section in Unaweep Canyon over the period of one month. The recorded seismic data contain continuous ambient noise (traffic, quarry activities) as well as several teleseismic earthquakes. The seismic ambient noise is subjected to interferometric analysis to reconstruct surface waves propagating through the array. Those surface waves show clear dispersive behaviour in the frequency range 1–6 Hz, allowing to image the 2D-shear wave velocity structure of the sediments down to maximum depths of ca. 400 m. The bedrock depth is imaged from auto-correlation analysis of the coda waves of the teleseismic events. Assuming near-vertical incidence of planar P-waves, auto-correlation can approximate the vertical reflectivity structure below the recording stations. Compared to the ballistic (first) arrival, the coda waves exhibit higher frequencies which are crucial to image the shallow bedrock interface. We obtain a very sharp image of an undulating bedrock interface along the entire section, which is also validated by a recent drilling result. Depending on the choice of the velocity model, the maximum depth of the bedrock along the investigated section is ca. 500 m. The structure suggests that the valley has been glacially overdeepened, although the lack of a 2D P-wave velocity model required for accurate depth conversion and the intricate 3D-structure of the canyon leave some uncertainty on this interpretation. We conclude that passive seismic imaging is a meaningful and cost-effective method to investigate local and regional structures, in particular in areas with difficult access. While ambient noise is required for velocity modelling and might not always be prevalent, teleseismic events are abundant everywhere and the frequency content of their coda waves can be high enough for shallow reflectivity imaging.

The central Styrian Basin (Gnas Subbasin): Structure and stratigraphy revealed by seismic and borehole data

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The Gnas Subbasin represents the central part of the Neogene Styrian Basin in the southeast of Austria. Despite decades of exploration activity for hydrocarbons, the formation mechanisms and the basin architecture are still poorly understood. To increase our understanding, seismic lines and well data, provided generously by RAG Austria AG and OMV were re-interpreted. The subsurface data gives new insight into basin depth and geometry, tectonic patterns and the stratigraphy of the Neogene basin fill. For instance, seismic data reveals that the basin depth exceeds 4 km below ground level. Seismic interpretation further allowed to reconstruct the tectonic evolution of the basin. Basin evolution was initiated by extreme crustal extension in the lower Miocene, activating a detachment horizon within the pre-Neogene basement. Synsedimentary low angle normal faults, arranged in a radial, most likely en-echelon pattern around the basin centre, dissected the hanging wall of the detachment into fault blocks, resulting in a pronounced relief of the pre-Neogene basement. Consequently, coarse-grained sediments were deposited in alluvial fans and fan delta complexes in early Miocene time. Furthermore, seismic data show that the Carpathian synrift deposits cover significant parts of the subsurface of the Gnas Subbasin and reach a thickness of at least 2 km in the depocenter of the basin. Major fault activity ceased around the Carpathian/Badenian boundary (i.e., Styrian Tectonic Phase). The up to 1,200 m thick Badenian succession is characterized by turbidite deposits and lower Badenian lava flows in central parts of the subbasin. On isolated highs, in contrast, lower and middle Badenian Leitha Limestone formed. The Sarmatian succession is characterized by a merging of the various depositional environments into a unified, shallow marine environment. The thickness of Sarmatian strata is up to 800 m. The Sarmatian can be described by a 3rd order sequence which further subdivides into five 4th order sequences. The Pannonian succession is characterized by a uniform, fluvial-limnic-deltaic depositional environment. Post-Pannonian compression resulted in crustal-scale folding and significant uplift along the basin margins. In contrast, inversion of faults cannot be observed in seismic data.

Towards an analytical proof of origin for natural graphite

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Natural graphite is a critical high-tech raw material of great importance. Unfortunately, Europe's high-tech companies are currently reliant on foreign graphite. Looking at the supply, China (67 %) took the top spot for the graphite world production in 2021, followed by Brazil (7 %) and Mozambique (5 %). Other supplier countries, such as North Korea, Russia and Ukraine are also not emerging as the most stable countries and the supply cannot always be ensured. With its high electrical and thermal conductivity, excellent thermal stability and lubricity, graphite is suitable for a wide range of industrial applications. Graphite is indispensable in lithium-ion batteries, which are used in everything from phones to electric vehicles. The demand for those products is likely to emerge within the next 30 years. Thus, the demand for graphite is estimated to rise by nearly 400 % within the next 30 years. The aim of this research project is to develop methodical approaches for an analytical proof of origin procedure for graphite. Different deposits distributed worldwide are included in the project. The analytical proof of origin for graphite aims to differentiate between various origins of the material, in particular from African countries, but also from Korea, China, Brazil and others. Graphite offers several options for an analytical proof of origin. A meaningful combination of the methods allows to decipher geological and mineralogical processes and define the source of a material as unique. The parameters must be robust to alteration or other changes of the raw material itself. Also, the applied parameters must be easy to reproduce and the analytical methods must be widely available. In case of changes during later geological history (e.g., diagenesis, metamorphism), some geochemical characteristics must be preserved to an extent that the original chemical signature is still recognizable. Therefore, the following parameters are considered as useful and important: 1) Geochemical parameters such as minor and trace element compositions and isotopic ratios of carbon and possibly sulphur allow conclusions about depositional processes. 2) Crystallographic parameters (e.g., d-values in XRD and Raman spectral parameters) allow conclusions about the prevailing metamorphic P-T conditions and 3) Grain morphology as assessed by microscopical work (e.g., SEM and light microscopy) is controlled by crystal growth but also weathering and abrasion, being important indicators of the sample origin. 4) The mineral paragenesis is another important parameter to decipher the geologic history of the sample, assessed through detailed in-situ microscopic studies or XRD analysis. Analytical proof of origin (APO) methods in general are regarded as the least corruptible methods, as they directly relate to the chemical composition of the raw material. Other methods such as conventional documents, tracers, QR codes and barcodes can be outmaneuvered in one way or another. The approach of the analytical proof of origin at the same time poses challenges in terms of costs, flexibility and cooperation between companies and the willingness to implement. The most plausible application of APO is seen in the case of conflict minerals and precious metals. In the future it might also be applied to critical minerals that are essential for the future development of our industry and society, although the supply is heavily dependent on certain supplier countries.

Sekundärminerale in Pb-Zn-Lagerstätten und Ermittlung der Elementgehalte am Beispiel der Halden in Bleiberg, Kärnten

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Das Thema der Ressourcenknappheit beschäftigt Wissenschaftler*Innen verschiedenster Sparten – von Mineralogie und Geochemie über Aufbereitung hin zu Metallurgie. Dabei nimmt die Tendenz zur Rohstoffwiedergewinnung aus bereits verarbeitetem Material immer mehr zu. Weltweit türmen sich Halden von Schlacken aus der Metallindustrie und solche mit Abraum aus Bergbaubetrieben. Nicht nur sind diese Halden sehr kostspielig und müssen Umweltauflagen erfüllen, auch stecken in ihnen noch gewisse Mengen an wertvollen Stoffen. Das COMET-Projekt „Competence network for the assessment of metal bearing byproducts“ (COMMBY) der Montanuniversität Leoben steht in Kooperation mit diversen Industriepartnern und beschäftigt sich mit eben dieser Thematik. Zusammen mit der GKB-Bergbau GmbH werden vorrangig drei von den über 200 Bleiberger Halden mit geschätzten 3 Mio. m^3 Material auf ihren Metallgehalt – v.a. Blei, Zink, Molybdän und Cadmium – untersucht. Dafür erfolgten Probenahmen im Jahr 2019 mittels Schreitbagger an den Halden Matthäus, Altstefanie und Glück, sowie 2021 mittels Spaten auf der Matthäus-Halde. Im Fokus steht der Vergleich von Analysemethoden. Messungen mit portabler RFA (pRFA) im Feld zeigen im Vergleich zu RFA an Schmelzpillen und pRFA an Pulvern sehr abweichende Werte. Wiederrum finden sich in den Schmelzpillen deutlich geringere Pb-Gehalte. An den im Jahr 2021 entnommenen Proben der Matthäus-Halde wurden mittels RFA 0,06 % Mo, 0,13 % Zn und 0,67 % Pb als Median der Gesamtgesteinsanalysen aller Probenahmepunkte bestimmt. Für die im Jahr 2019 entnommenen Proben wurden Schwimm-Sink-Analysen durchgeführt, um verschiedene Korngrößenfraktionen in Leichtgut (< 2,67 g/cm^3), Mittelgut und Schwergut (> 3,0 g/cm^3) einzuteilen. Die Gehalte der Matthäus-Halde im Schwergut für die Korngrößen 1–0.1 mm betragen im Mittel fast 4 % Mo und ~16 % Zn. Der Gehalt an Molybdän ist auf den Halden Altstefanie und Glück geringer. Die Pb-Gehalte konnten an Pulverpresslingen und mittels ICP-MS auf über 20 % für die Schwergutfraktion bestimmt werden. Für die mineralogische Charakterisierung wurde mit einem Rasterelektronenmikroskop und dem Programm SmartPI™ der Firma ZEISS gearbeitet. Die Verwendung dieser „Smart Particle Investigation“ ermöglicht eine Flächenmessung von Partikeln mit grafischer Darstellung und automatischer Mineral-Zuweisung. Die wichtigen Metalle sind an die Minerale Wulfenit (Mo), Galenit (Pb), Cerussit (Pb), Sphalerit (Zn, Cd, Ge) und Smithsonit (Zn) gebunden. Ab einer Korngröße < 0,3 mm liegen die metallreichen Partikel größtenteils frei vor. Ein Anteil der Schwermetalle ist an schwer lösliche, feinkörnige Eisenoxyhydroxide gebunden. In den gröberen Fraktionen sind die Wertmineralphasen im karbonatischen Nebengestein eingebettet oder mit Gangartmineralen (Karbonat, Schwerspat, Flussspat, Quarz) verwachsen. Mittels Röntgendiffraktometrie konnten für die Schwergut-Kornfraktion 100/40 µm der Matthäus-Halde fast 70 % Cerussit, ~8 % Galenit und ~9 % Wulfenit als Wertminerale bestimmt werden. Die wellenlängendispersive Elektronenmikrosondenanalyse wurde zur Unterscheidung von Pb-, Mo- und S-haltigen Mineralen verwendet. Die Kombination der chemischen und mineralogischen Untersuchungen mit aufbereitungstechnischen Versuchen ermöglicht eine Neubewertung des Haldenmaterials als zukünftige Rohstoffquelle.

Recent to past record of lacustrine chalk deposition and diagenesis in Weissensee (Carinthia, Austria)

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Our field site Weissensee is located in Carinthia (Austria) at 930 meters above sea level and is widely known for its light-coloured, lacustrine chalk deposits that are partially seaming the shore of the lake. Recent findings indicate that the formation of these calcitic chalk deposits is closely related to calcium carbonate mineralization mediated by extracellular polymeric substances (EPS). However, the interactions between the hydrosphere and EPS, as well as the influence of different environmental parameters on the formation mechanisms of $CaCO_3$ are not yet fully understood. The potential of this sedimentary archive as an important local sink for CO_2 moreover demands further research. Therefore, this project aims to gain a better understanding of the underlying processes for EPS-mediated carbonate production, diagenetic alteration, and potential precursor calcium carbonate transformation. Down-core sediment sampling of two sediment cores, recovered from two different locations within Weissensee, allows a high-resolution investigation of the recent to past deposition. Mineralogy, geochemistry and micro-morphologies are studied via a multi-proxy approach in order to reveal the potential of the investigated archive as a reliable carrier for environmental (paleo)proxies. Preliminary findings at the western part of the lake (core sample E3) show that – besides biogenic components – the sediments of the upper 10–15 cm of the core are mainly composed of authigenic calcite and detrital dolomite, with a distinct shift in the calcite/dolomite ratio. This shift is correlated with a change from low-Mg calcite to high-Mg calcite. Framboidal pyrite can be observed throughout several layers of the sediment core, indicating bacterial sulfate reduction. Moreover, X-ray fluorescence data suggest an increase in detrital input in the upper part of the core. Stable C and O isotope analyses of the carbonates and radiocarbon dating of organic compounds are in progress, providing lacking evidence of depositional ages and sedimentation rates.

Erdwärmenutzung am Beispiel von Erdwärmesonden in der Steiermark

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Die Nutzung der erneuerbaren, nicht fossilen Ressource „Erdwärme“ in Form von Erdwärmesonden (Tiefsonden) erfreut sich im Bundesland Steiermark wachsender Popularität. So wurden seit dem Jahr 2011 allein südlich der Mur-Mürz-Furche etwa 2.000 Vorhaben mit insgesamt mehr als 6.000 Bohrungen wasserrechtlich bewilligt und umgesetzt. In Kombination mit Wärmepumpen werden Erdwärmesonden zur Beheizung (und in zunehmendem Ausmaß auch zur Kühlung) von Einfamilienhäusern, Wohnanlagen und Gewerbeobjekten verwendet. Dabei kommen hauptsächlich einfache U-Rohr-Erdwärmesonden zum Einsatz. Die sich stetig erhöhende Anzahl von Erdwärmesonden ist jedoch für das Grundwasser mit Problemstellungen und Risiken verbunden. Hierbei sind im Wesentlichen die Durchörterung schützender Deckschichten von Grundwasserleitern und die Gefahren der mangelhaften Ausführung der notwendigen Bohrarbeiten, der nicht fachkundigen Ansprache/Dokumentation der bei den Bohrarbeiten angetroffenen Lockersedimente/Festgesteine sowie der unsachgemäßen Verpressung des Ringraumes (Möglichkeit der Herstellung hydraulischer Kurzschlüsse) zu erwähnen. Als zusätzliche Herausforderung ist das Vorhandensein von gespanntem oder artesisch gespanntem Grundwasser in der West- und Oststeiermark, dem Mittleren und Oberen Ennstal, dem Mitterndorfer Becken und dem Ausseerland zu berücksichtigen. Dieses kann in manchen Teilen der Oststeiermark außerdem mit Drücken von mehr als 0,3 bar angebohrt werden. Die thermischen Auswirkungen des Betriebs von Erdwärmesonden auf das Grundwasser sind als weitere, bislang noch nicht umfassend betrachtete Themenstellung anzusehen. Zur Veranschaulichung der technischen und rechtlichen Mindestanforderungen sowie als Planungsgrundlage für die Errichtung von Erdwärmesonden wurde vom Amt der Steiermärkischen Landesregierung im Jahr 2011 erstmals ein Strategiepapier mit dem Titel „Die Gewinnung von Erdwärme in Form von Vertikalkollektoren (Tiefsonden)“ veröffentlicht. In diesem Strategiepapier werden die Grundwasserkörper mit gespannten oder artesisch gespannten Grundwasservorkommen im Bundesland Steiermark („Steirisches und Pannonisches Becken“, „Oststeirisches Becken“, „Weststeirisches Becken“, „Mittleres Ennstal“, „Oberes Ennstal“ und „Traun“) in drei Zonen unterteilt. Im Rahmen des wasserrechtlichen Bewilligungsverfahrens sind in diesen drei Zonen bei der Errichtung von Erdwärmesonden – je nach Risikopotenzial für das gespannte oder artesisch gespannte Grundwasser – unterschiedliche Auflagen einzuhalten. Dazu darf ergänzend festgehalten werden, dass im Bereich der oben angeführten sechs Grundwasserkörper eine wasserrechtliche Bewilligung prinzipiell im Anzeigeverfahren gemäß § 114 WRG 1959 erfolgt. Ist hingegen eine Beeinträchtigung fremder Rechte oder (z.B. bei Sondenfeldern) eine thermische Auswirkung auf das Grundwasser zu erwarten, muss ein Bewilligungsverfahren nach § 32 WRG 1959 durchgeführt werden. Die in den vergangenen zehn Jahren gewonnenen Erkenntnisse und neue technische Entwicklungen führten schlussendlich zur Notwendigkeit der Überarbeitung des Strategiepapiers, welche Anfang Juni 2022 in Form des neu veröffentlichten „Strategiepapiers Erdwärme 2.0“ abgeschlossen wurde.

Formation processes and prevention strategies of scale deposits in tunnel drainage systems

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Calcium carbonate scale deposits ($CaCO_3$ mineral precipitation from aqueous solution) in drainage systems and water circuits are a common and challenging issue, especially if deposition and clogging limit the water flow. Maintenance work including various mechanical removal of the unwanted mineral deposits causes high costs and major traffic disturbances. This argues for an optimized case-specific process understanding regarding variable scale material characteristics, sedimentary dynamics, its environmental control and sustainable prevention strategies. Geogenic presetting, such as the chemical composition of local groundwater and (hydro)geological framework, as well as technical-operative conditions, such as interaction with cementbound building materials, the drainage design (flow geometries) or the use of chemical additives (inhibitors), affect the specific formation mechanisms and consequently the appearance, composition and consistency of the scale deposits. Microbes such as chemolithoautotrophic bacteria can significantly influence scaling reactions and should also be evaluated in the case-specific prevention strategies. The eco-friendly inhibitor polyaspartate (PASP) was tested and assessed in order to reduce and modify the amount, consistency and (micro)structure of the predominant $CaCO_3$ scale deposits. Dosage of small amounts of PASP results in (i) a substantial inhibition of $CaCO_3$ formation, (ii) a more porous or even loose scale consistency (calcareous mud), and (iii) a shift in $CaCO_3$ mineralogy from predominant calcite toward vaterite. A few parts per million of PASP can induce a saturation index in respect to calcite of about 2, i.e. close to the saturation level of amorphous calcium carbonate (ACC). The research activities presented combine-promising results with regard to fundamental carbonate research as well as practical technical solutions in the context of tunnel maintenance.

Unterschiede in der Störungskartierung von potentiellen Endlagern aufgrund alternativer seismischer Processingvolumen

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Die Identifizierung und Charakterisierung von tektonischen Störungen im Untergrund sind Schlüsselaspekte geologischer Interpretationsstudien für die Endlagersuche von radioaktiven Abfällen. Im äußersten Vorland der europäischen Zentralalpen (nördlichstes Molassebecken) wurde der Einfluss unterschiedlicher seismischer Processingprodukte auf die Kartierung von tektonischen Störungen untersucht. Die Interpretationen der unterschiedlichen 3D-Seismiken erfolgte in den letzten 5 Jahren und beinhaltete ein erstes Processingvolumen in Zeitdomäne, gefolgt von einer Pre-Stack Depth Migration und schließlich einem Refinementprocessing in Zeitdomäne. Zusätzlich standen für jede dieser drei Phasen unterschiedliche Produktvarianten zur Verfügung. Diese Produktvarianten unterscheiden sich in einzelnen Processingparametern, verwendeten Algorithmen und teilweise auch in der durchführenden Processingfirma. Jedes seismische Volumen wurde individuell interpretiert und zusätzlich seismische Attribute für diese berechnet. Der Vergleich der unterschiedlichen Dateninterpretationen ergab konsistente Ergebnisse bezüglich der Kartierung der seismischen Markerhorizonte und Hauptstörungssegmente. Abweichungen betreffen vor allem laterale und horizontale Segmentierung von einzelnen Störungen sowie eine unterschiedliche Visualisierung von kleinräumigen Störungsflächen. Mit Hilfe von Darstellung der jeweiligen Störungslineamente auf ausgewählten Markerhorizonten werden die einzelnen Interpretationsergebnisse kritisch bewertet und hinsichtlich ihrer Robustheit schließlich in unterschiedliche Klassen geteilt. Durch den Vergleich der unterschiedlichen Interpretationsergebnisse können Unsicherheiten in den einzelnen Processingprodukten berücksichtigt werden und damit auch Interpretationsunsicherheiten besser aufgezeigt werden.

Anwendung von hochauflösenden Sub-Bottom Profiling Daten zur Darstellung seichtliegender Sedimente in Flüssen und Staubecken

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Sub Bottom Profiling (SBP)-Systeme sind akustische Messsysteme mit hoher Auflösung zur Abbildung seichter Sedimente, die normalerweise aus einer auf einem Schiff montierten Einkanalquelle bestehen. Ihr Anwendungsgebiet reicht von der Beschreibung von seichtliegenden Sedimenten in Flüssen und Seen, der Visualisierung von Unterwassermassenbewegungen bis hin zum Detektieren von Objekten. Ähnlich wie bei einer üblichen seismischen Reflexionsuntersuchung senden diese Quellen Schallimpulse in die seichten Sedimente des Fluss- oder Seeuntergrunds. Schallimpulse werden dann an Sedimentschichtgrenzen reflektiert, wo Unterschiede in der akustischen Impedanz der oberen und unteren Schicht vorhanden sind. Die reflektierten Schallimpulse werden dann vom SBP-Messsystem aufgezeichnet. Dieses Verfahren wird typischerweise entlang einer 2D-Linie wiederholt und die einzelnen Spuren werden zusammengesetzt, um einen seismischen 2D-Schnitt zu erzeugen, der dann in einem seismischen Interpretationssoftwarepaket interpretiert werden kann. Zur Erfassung von SBP-Daten stehen verschiedene Messsysteme zur Verfügung, die sich in Art der Quelle, Auflösung und Frequenz und damit auch in der Eindringtiefe unterscheiden. Dabei haben „Sparker“ (50 Hz bis 4 kHz) Systeme mit bis zu 1.000 m die höchsten Eindringtiefen, „Boomer“ (500 Hz bis 5 kHz) Systeme erreichen bis zu 100 m und „Pinger“ (3,5 kHz bis 7 kHz), „Chirper“ (3 kHz bis 40 kHz) und „Parametric“ (100 kHz) Systeme haben eine Eindringtiefe von weniger als 100 m. In diesem Projekt wurden 48 SBP-Profile mit unterschiedlichen Frequenzen im Ausgleichsbecken des Wasserkraftwerks Rottau im Mölltal, Kärnten, mit Hilfe eines parametrischen Messsystems aufgenommen. Die aufgenommenen Daten waren aufgrund starkem Unkrautbewuchs in einigen Bereichen des Ausgleichsbeckens und aufgrund unterschiedlicher Erfassungsgeschwindigkeiten teilweise mit Störsignalen behaftet. Um das Signal-Rausch-Verhältnis zu verbessern, wurde eine strukturorientierte Filterung angewendet. Ungefähr ein Jahr nach der Erfassung der SBP-Daten wurden auch elf flache Sedimentkerne zur Kalibrierung der Interpretation der SBP-Profile entnommen. Die Interpretation der SBP-Daten basiert auf einem sequenzstratigraphischen Ansatz, bei dem Reflexionsterminierungen (Onlaps, Downlaps und Toplaps) und seismische Faziesänderungen verwendet werden, um Sedimentpakete zu interpretieren. Basierend auf diesem Interpretationsansatz konnten sieben verschiedene Sedimentpakete innerhalb des Ausgleichsbeckens und drei Sedimentpakete innerhalb der angrenzenden Möll interpretiert werden. Nach der seismischen Interpretation und dem Gridding-Prozess wurde ein Strukturmodell sowohl für das Ausgleichsbecken als auch für die Möll für eine spätere volumetrische Abschätzung von Sedimentpaketen erstellt.

Assessing analytical methods for high precision Ni isotopic analysis in rhizosphere samples from Ni hyperaccumulating plants

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The identification of the change in the isotopic composition of Ni is a powerful tool with high potential to assess mechanisms and pathways of biogeochemical processes like the study of Ni isotope ratio variations between bedrock and chemical fractions in soils and in plants. Ni is a bio-essential trace element, which was observed to show mass dependent isotope fractionation in geochemical as well as biological processes. Soil solutions, iron oxides and clay minerals were reported to be more enriched in the heavier Ni isotopes compared to their respective parent bedrock. However, the range of Ni isotope fractionation in biological processes was observed to be significantly larger compared to abiotic processes. As such, studies of Ni isotope composition in geological and biological samples may be a valuable proxy helping to understand solubilization in the rhizosphere and interactions in the plant soil microbe system. However, routine measurements of Ni isotope ratios are currently hampered by complex sample preparation procedures such as laborious Ni – matrix separation and difficulty to obtain isotope ratio results with the required low measurement uncertainties using multi collector inductively coupled plasma mass spectrometry (MC-ICPMS). This contribution compiles the first results from the FWF funded project (P 34719) “Mobilisation of Nickel by hyperaccumulating plants” to investigate Ni solubilisation processes in the rhizosphere of Ni hyperaccumulating plants. Refined analytical protocols for sample preparation, Ni – matrix separation and Ni isotope ratio measurements with the use of a novel MC-ICP-(CRC)-MS are reported.

Hydrogeophysical survey in the St. Ilgener valley revealing subsurface structure and groundwater pathways

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The Hochschwab massif is a major karst system in eastern Austria, providing water supply from its springs at the northern margin to the city of Vienna. The St. Ilgen aquifer, located at the southern margin of the Hochschwab massif, contributing water to the Central Water Supply Hochschwab South (ZWHS), is a roughly 200 m thick sediment body that is mainly sourced by surface and subsurface recharge from the Trawiestal. There are groundwater monitoring wells and precipitation measurement stations. The localized basin fill is known from earlier geophysical and hydrogeological studies, as well as from boreholes, and it largely consists of alternating layers of gravels, sands and clays. However, the detailed structure of the aquifer sediments and preferential groundwater pathways are still largely unknown due to the lack of spatiotemporal subsurface information. In this study, we applied electrical resistivity tomography and ground penetrating radar in order to determine the depth of the bedrock (“Werfener Schichten”) and to identify the water table in the Bodenbauer – St. Ilgener Tal area. Electrical resistivity tomography (ERT) data were collected from two ~400-meter-long profiles, oriented parallel with (P1) and perpendicular to (P2) the valley axis in the upper part of the St. Ilgener valley in dipole-dipole and pole-dipole modes. P1 reveals a mostly horizontal, highly conductive formation at depths between 15 and 60 meters, which we attribute to be the representation of the aquifer. The water bearing zone could also be detected as suggested by the high conductive zone in the intersecting cross-profile P2 with a matching water table depth of ~20 m and a saturated sediment thickness of 40–50 m. However, in its southwestern extension, P2 shows a depth shift of the water-saturated zone with a possible water table depth at ~70 m. The water-saturated sediment zone extends over a thickness of 50–60 m and is covered by a remarkably high-resistivity layer (> 1,000 Ohm.m) in the central part of the profile. Both P1 and P2 are unlikely to reach the bedrock. The preliminary ERT results indicate that the St. Ilgener valley aquifer system comprises a complex and heterogeneous internal structure with three postulated compartments. The hydraulic communication between the water-saturated zones in the central part of the St. Ilgener valley is tentative and must be clarified by additional investigations, such as time-lapse measurements.

Shark diversity at the K/Pg boundary in Austria – A tale of extinction and hidden survival

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Deep-sea environments are thought to provide potential refuge environments during catastrophic events for chondrichthyans. Although the K/Pg boundary represents one of the five mass extinction events in the Phanerozoic, little is known about its consequences over elasmobranch evolution and ecological structure of shark faunas. Here, we present an extensive study of deep-marine sediments, spanning the Cretaceous-Palaeogene boundary in Waidach, near Salzburg (Austria). The sediments comprise shelf deposits from the south Helvetic Nappe System and were deposited at a supposed palaeolatitude of 30°N. The detailed sampling of nine horizons, which represents in total about 1,500 kg of sediment, revealed more than 2,000 ichthyoliths representing teeth and dermal denticles of cartilaginous and bony fish. Considering the limited knowledge on the immediate aftermath of the impact or the cascade of changing environmental conditions on chondrichthyans at the K/Pg boundary, this study provides essential and unique high-resolution documentation of changes in shark diversity spanning this crucial time-interval. Thus, these extraordinarily rich assemblages further allow for precise snapshots unlocking the magnitude of demise on deep-water sharks and the time span for faunal recovery on a regional scale with a special emphasis on dogfish sharks (Squaliformes). These predominately deep-dwelling sharks diversified in the Late Cretaceous, making this location a hotspot for studying the evolution and diversification of this group in the Tethyan realm.

A new proposal for the Middle-Late Triassic paleogeography and tectonic evolution of the central Northern Calcareous Alps (Austria)

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The Northern Calcareous Alps (NCA) (Eastern Alps) were dominated through most of the Middle to Late Triassic by shallow water conditions in a post-rift setting, with the widespread deposition of thick platform carbonates (namely the Wetterstein and Dachstein limestones and dolomites). These shallow water Triassic platform carbonates dominate the outcrop of the NCA. In the area of the Salzkammergut in the central NCA the dominance of shallow water limestones is interrupted by the frequent appearance of geographically restricted outcrops of time-equivalent deep-water carbonate deposits (informally grouped into the Hallstatt facies), typically in association with Permian-age evaporite bodies of the Haselgebirge Formation. The distribution of deep and shallow water carbonates during the Triassic in the central NCA has been found to correspond to the areal distribution of structures cored by the Haselgebirge evaporites. These evaporite structures were mostly broad salt ridges (few hundreds of meters to few kilometers wide) that stretched forming a network of NW-SE and SW-NE structures. These orientations are inferred to correspond to the inherited passive margin structure of the underlying pre-Permian basement. During Permian to Early Triassic rifting, extension in the NCA was accommodated along SW-NE structures, with NW-SE structures acting as relay or transfer zones. During the post-rift the Haselgebirge nucleated salt ridges above these structures and further acted as a gliding surface for the Middle to Upper Triassic post-rift sedimentary units. Gliding of the sedimentary package led to differential development of the NW-SE and SW-NE directed salt structures. In contrast to the rifting phase, the structures in the SW-NE experienced limited extension whereas the NW-SE structures concentrated the greatest amounts of extension. As a result, SW-NE structures grew as diapiric structures at or near the seabed up to the Late Triassic, before being mostly covered by Upper Triassic platform carbonates. NW-SE structures in contrast developed as subsiding salt ridges, with a pronounced negative bathymetry around an axial swell. It is in these NW-SE oriented structures that the Hallstatt Facies were preferentially deposited, flanked by units that transitioned into the surrounding shallow water reefs and platforms. This relatively simple picture has been strongly overprinted by younger tectonic events including Late Jurassic shortening of the salt structures, Early Cretaceous Eoalpine thrusting, Late Cretaceous development of synorogenic basins, and Neogene strike-slip tectonics associated with lateral extrusion. All of these events recycle the original salt-cored structures in different, and sometimes complex, ways. Of particular relevance is the Late Jurassic shortening episode, as it is the one that is mainly responsible for the closure of the largest evaporite bodies and the juxtaposition of Triassic shallow and deep water carbonates. The proposed tectonic evolution is based on an integrated tectono-sedimentary approach and has an impact on the understanding of the early stages of Alpine orogenesis in the Eastern Alps and of the relative contribution of salt tectonics in the post-Triassic structural evolution.

Erdwissenschaftliche Angebote für Schulen im Schuljahr 2022/2023

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Seit 1998 bietet die Sammlung Geologie & Paläontologie (Universalmuseum Joanneum) für Schulklassen ein umfangreiches Exkursionsprogramm für alle Schulstufen zu den Themen Geologie (allgemeine Geologie, regionale Geologie, mineralische Rohstoffe) und Paläontologie (Fossilien und deren Bedeutung). Projekte für das Schuljahr 2022/2023 werden kurz vorgestellt: Sonderausstellung: „Auf Spurensuche … durch die Erdgeschichte“, Ort: Naturkundemuseum im Joanneumsviertel, A-8010 Graz; Zeit: ab 16. September 2022 bis Juli 2023. In der Erdgeschichte kennen wir vielfältige Spuren, die von ehemaligen Lebewesen, deren Lebensweise, von verschwundenen Ökosystemen sowie insgesamt der Entwicklungsgeschichte des Lebens erzählen. Wir zeigen und erklären die Entstehung und Erhaltungsmöglichkeiten von Lebensspuren und weisen auf deren Bedeutung hin. In Gesteinen finden wir aber auch Spuren von vergangenen Landschaften, von Urmeeren und ehemaligen Gebirgen, vom Wandel des Klimas und gelegentlich können wir auch Ereignisse mit regionaler oder globaler Auswirkung entdecken. Neben den Kräften im Inneren der Erde formen und modellieren auch jene Prozesse, die an der Erdoberfläche wirken, das Aussehen unseres Planeten. Die dabei entstehenden Spuren belegen die fortwährende, teilweise dramatische Veränderung unserer dynamischen Erde. Workshops und Exkursionen: Wir bieten für Schulen Ganztagesexkursionen an, bei denen geologische und paläontologische Themen in einem Modulsystem – in Absprache mit den Schulen – zusammengestellt werden können. Diese Module beinhalten neben der wissenschaftlichen Begleitung auch angewandtes Arbeiten zum Kennenlernen und Anwenden fachspezifischer Methoden im Rahmen von 1-Tages-Ausflügen. Jede Region hat, bedingt durch die geologische Entwicklung, ihren eigenen Charakter. Der Zusammenhang zwischen Geologie und Landnutzung, aber auch die rohstoffwirtschaftliche Bedeutung der geologischen Entwicklung wird im Gelände an konkreten Beispielen erarbeitet und diskutiert. Die Schüler/Innen werden selbstständig entdecken und erkennen. „Vom Handstück zur Landschaft“: Strukturen, Formen und Einschlüsse (z.B. Fossilien) in Gesteinen spiegeln ehemalige Ökosysteme, erdgeschichtliche Ereignisse und geologische Prozesse wider. Im Kalksteinbruch Retznei werden wir auch im kommenden Sommersemester wieder einige Workshop-Tage (Fossilien suchen und präparieren) für Schulklassen anbieten können. Auch unsere Exkursionen im Steirischen Vulkanland werden wir unter dem Motto „Auf Spurensuche … im Steirischen Vulkanland“ fortsetzen. Vom 15.–17. Mai 2023 findet im Steirischen Vulkanland die Internationale Tagung GeoTop 2022 unter dem Motto „Inwertsetzung der Geologie als Fundament für die Regionalentwicklung“ statt. Täglich werden vormittags Vorträge und nachmittags Exkursionen angeboten. Zielgruppe: Tourismusbranche, Pädagoginnen und Pädagogen, alle an Erdwissenschaften interessierten Laien.

Pharos – ein Einstiegsportal in das Datenarchiv des Geologisch-Mineralogischen Landesdienstes Steiermark

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Der Geologisch-Mineralogische Landesdienst Steiermark (GMLD) ist ein Zusammenschluss der am Land Steiermark beschäftigten Erdwissenschaftler zum Zwecke der Koordinierung der fachbezogenen Aufgaben des Landes. Die zuständigen Amtssachverständigen sind unterschiedlichen Fachabteilungen des Landes zugeordnet. Das zentrale Archiv und die Auskunftsstelle für wissenschaftliche Fragestellungen sind in der Geologie & Paläontologie am Universalmuseum Joanneum angesiedelt. Im Zuge von VALL-Projekten (Vereinigung für Angewandte Lagerstättenforschung Leoben) mit Mitteln der Wissenschaftsabteilung des Landes Steiermark konnten umfangreiche unveröffentlichte Berichte und Daten aufgearbeitet und allgemein zugänglich gemacht werden. Heute bietet die Website www.gmld.at als erdwissenschaftliches Archiv der Steiermark umfangreiche Sammlungen an, die als georeferenzierte Datenbanken digital abrufbar sind. Es handelt sich dabei neben geotechnischen Daten (z.B. Bohrungen, Geophysikdaten) auch um Informationen zu Lagerstätten, Baurohstoffen, Dekorgesteinen und Archivdaten (Gutachten, geologische Spezialkarten, unveröffentlichte Berichte von Fachinstitutionen). Daneben werden auch laufend die Objekte der Sammlung der Geologie & Paläontologie des Universalmuseum Joanneum (Gesteine, mineralische Rohstoffe, Fossilien, montanhistorische Objekte) in die Datenbank eingepflegt. Sämtliche Metadaten sowie teilweise auch weiterführende Details und Bildmaterial sind im GIS Steiermark öffentlich zugänglich und geographisch abrufbar. Seit 2016 gibt es auf www.gmld.at zusätzlich die indexbasierte Suchmaschine „Pharos“, mit der einfach, schnell und übersichtlich diese Daten abgerufen werden können. Dies erfolgt entweder durch Eingabe von Stichworten zu den Metadaten oder über eine Ortssuche. Die Daten können als Punkte oder Polygone frei wählbar entweder auf einer topographischen (basemap) oder geologischen (GEOFAST) Karte bzw. mit dem Orthofoto hinterlegt dargestellt werden. Bei einer größeren Agglomeration an Daten werden die Punkte zusammengefasst angezeigt und bei Änderung des Zoomlevels automatisiert direkt reorganisiert. Diese Suchmaschine wird neben der weiteren technischen Verbesserung laufend mit neuen Inhalten ergänzt: z.B. wird es durch die Implementierung von Gemeindepolygonen auch möglich, mit der Eingabe eines Gemeindenamens sofort alle vorhandenen Punkte/Flächen im Gemeindegebiet dargestellt zu bekommen.

The Eastern Greywacke Zone – a 400 Ma story from Gondwana decay to Alpine assembly

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The Greywacke Zone (GWZ) was originally defined as the hilly domain between the Northern Calcareous Alps and the “crystalline” rocks of the central axis of the Alps. Despite of this insignificant description from the 19th century it turned out that the units exposed contain information relevant for Early Paleozoic break-off of north Gondwana fragments, two Paleozoic orogenies, closure and obduction of Meliata oceanic fragment and distribution of early Alpine nappes. The area of interest consists, from tectonic bottom to top, of the Veitsch Nappe, a sequence of Carboniferous shallow marine molasse sediments and the Silbersberg Nappe, a succession of Permian metaclastics interbedded with acidic and basic volcanics. Slices of amphibolite and gneiss (“Kaintaleck slices”) are either interpreted as part of the Silbersberg Nappe or as individual Kaintal Nappe. The greatest extend by area is represented by the Tirolic-Noric nappe system with Paleozoic metasediments and metavolcanics transgressively overlain by Permo-Mesozoic sediments in Tirolic facies. The uppermost tectonic unit is the Mürzalpen Nappe with Permo-Mesozoic sediments in Juvavic facies that are not part of the GWZ. The Tirolic-Noric nappe assembly consists of four internal nappes, the Hocheck, Rossegg, Steinbach, and Aschbach Nappes. All of them contain andesitic to rhyolitic metavolcanics that range in age between c. 480 and 445 Ma and are interbedded, in the Steinbach Nappe, by sandstones. The sediments within individual nappes differ significantly in facies. Upper Ordovician to Silurian shallow marine sediments occur within the Hocheck and Rossegg Nappes (Rad Formation) and continental slope deposits within the Steinbach Nappe (Stocker Formation). The Sommerauer Formation of the Aschbach Nappe contains turbidites interpreted as channel or lobe sediments deposited on the ocean floor. The pre-tectonic arrangement as derived from profile balancing gives a NW-SE arrangement of nappes and facies domains with continental slope deposits in the today’s northwest and a shallow marine platform in the southeast. The metavolcanics are interpreted to document magmatic pulses from the end of the Ceneric Orogeny to the opening of the Paleo-Tethys Ocean. Simultaneously with deposition of platform carbonates in the Noric Group an early, Eo-Variscan tectonic activity is recorded within the Kaintaleck metamorphic slices (c. 380 Ma). Undated tholeiitic basalts with MORB affinity evolved potentially already in the Late Neoproterozoic / Cambrian and accreted in the Middle Devonian. This Eo-Variscan event is further supported by c. 390 Ma old detrital zircons from Permian Silbersberg sandstones that document existence of a Middle Devonian magmatic / metamorphic hinterland. Other detrital zircon spectra from Carboniferous and Permo-Mesozoic sediments of the Veitsch and Tirolic-Noric nappes show a pronounced Tournaisian peak (c. 356 Ma) documenting erosion from a second, Meso-Variscan source. The detrital zircon age data show also that the clastic Permo-Mesozoic sediments of individual nappes were not delivered from the same source. We argue for large-scale lateral displacement along transform systems when the Meliata Ocean was closing and Piemont-Liguria was opening, probably during the Jurassic. Final Meliata closure and accretion is evident from gabbro occurrences incorporated at the base of the Juvavic nappes, followed by topwest stacking along the Noric Thrust at conditions of c. 420 °C prior c. 100 Ma.

Distributed acoustic sensing: opportunities, challenges, and data highlights from railway installations in Austria

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Distributed Acoustic Sensing (DAS) is an emerging technology showing huge potential for seismological applications. The opportunities that rise from having a distributed vibrational sensor with meter-scale sampling over tens of kilometres may revolutionise the way we look at seismic wavefields. DAS may provide new and unprecedented observational windows for both imaging and monitoring the Earth's surface and subsurface. However, the amount of data generated by current DAS systems also introduces new challenges and requires intelligent and innovative data handling and analysis. At Sensonic GmbH we are global pioneers in applying DAS technology for railway applications. Using both anthropogenic and natural seismic signals we infer relevant information about trains, railways, and natural hazards in real-time. Here we introduce some of our current activities, and highlight several seismic events recorded by our installations in Austria, including earthquakes in Upper Austria and blasts from the Semmering tunnel construction site. Earthquakes recorded by our DAS systems highlight the amount of detail that is contained in the seismic traces, such as near surface reflections or refracted waves. At the same time the earthquake records reveal new challenges regarding the limited directional sensitivity of fiber optic sensors. We also highlight the struggles that originate from the huge amounts of data that we are collecting: a single DAS device collects 10 times more samples per second then all seismometers worldwide.

Spurenelemente in Zinkblenden aus der Blei-Zink-Lagerstätte Raibl

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In der Blei-Zink-Lagerstätte Raibl/Cave del Predil (Norditalien, Julische Alpen) wurde mehrere Jahrhunderte lang Bleierz, Zinkerz und deren Umwandlungsprodukte abgebaut. Im Jahr 1991 erfolgte die endgültige Heimsagung. Diskutiert wird sowohl eine epigenetische als auch eine syngenetische Entstehung. Die Blei-Zink-Vererzungen befinden sich im karnischen Schlerndolomit, welcher lokal als Dolomia Metallifera bezeichnet wird. Lokal reichen sie auch in die darüber liegenden Raibler Schichten hinein. Die Lagerstätte ist kupfer- und silberfrei, zeigt aber hohe Gehalte an Arsen, Thallium und Antimon. Bekannt sind auch die hohen Germaniumgehalte im Zinkerz. Auffallend sind die unterschiedlichen Farben der Raibler Zinkblenden. Beschrieben werden verschiedene Braunschattierungen (hellbraun, dunkelbraun, rotbraun, grünbraun), wobei aber Zinkblende auch als rote Blende (Blenda Rossa), gelbe Blende (Blenda Gialla) und graue Blende (Blenda Grigia) auftritt. Texturell wird beim Zinkerz zwischen Schalenblenden, lagigen Erzen, Farnerzen und Röhrenerzen unterschieden. Letztere stellen eine Besonderheit dar. Dieser Erztyp besteht aus hohlen oder gefüllten Röhren aus konzentrischen Lagen aus Bleiglanz, Zinkblende, Baryt oder Dolomit. Ziel der Untersuchung war es, die Spurenelementkonzentrationen verschiedener Zinkblendetypen zu charakterisieren. Die Digitalmikroskopie und die Rasterelektronenmikroskopie identifizieren und dokumentieren die Minerale und ermitteln texturelle Unterschiede. Die Zonierung der chemischen Zusammensetzung der verschiedenfarbigen Zinkblendetypen wurden unter UV-Licht visualisiert und die Spurenelementgehalte wurden mittels LA-ICP-MS analysiert. Die untersuchten Zinkblenden weisen zwischen 0,5 und 59 ppm Mangan, bis zu 6.973 ppm Eisen und bis zu 1.524 ppm Germanium auf. Der Cadmiumgehalt variiert zwischen 277 ppm und 7.640 ppm. In Oberflächengewässern nahe Raibl wurden erhöhte Thalliumgehalte nachgewiesen, in den untersuchten Zinkblenden erreichten diese bis zu 2.324 ppm. Verschiedene Farbtypen der Zinkblende weisen signifikante Unterschiede in der Spurenelementkonzentration auf. Rötliche und braune Zinkblenden haben höhere Eisen-, Arsen-, Thallium- und Germaniumgehalte zu verzeichnen, grünliche Zinkblenden hingegen sind mit der Ausnahme von Cadmium arm an Spurenelementen.

The Lower–Middle Miocene transition (Karpatian–Badenian) in the Krems Embayment (Central Paratethys)

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The Krems Embayment represents the westernmost fully marine depositional environments of the Karpatian and Badenian transgressions in the Central Paratethys. Four deep drill cores were investigated to analyse the bio- and lithostratigraphic, and tectonic relations. The investigated core sections cover the Karpatian Laa Formation (bio-zones M4, NN4), and the Badenian Grund Formation (M5b–M6, NN4–NN5). Important biostratigraphic indicators identified are *Praeorbulina glomerosa glomerosa*, *Praeorbulina glomerosa circularis* and *Orbulina suturalis* for the Grund Formation. The Laa Formation is indicated by the absence of *Praeorbulina*, *Orbulina* and *Globigerina falconensis*, low numbers of *Globorotalia bykovae*, and a prominent peak in *Helicosphaera ampliaperta* abundance at the end of the Karpatian. *Cibicidoides lopjanicus* and *Cassigerinella* spp. occur with high percentages in Badenian samples and show much longer stratigraphic ranges than known from literature data. The depositional gap at the Karpatian-Badenian boundary has a minimum duration of 0.41 million years in the Krems Embayment. The combination of bio- and lithostratigraphic data allows the correlation across major faults. The Diendorf Fault system played an important role during basin formation and was very active during the Early to Middle Badenian. The results of this study show the complex interaction of sedimentation, tectonic activity and paleo-biological developments in this peripheral part of a marginal sea.

Wulka catchment hydrogeochemistry and the formation of Ca-Mg carbonate minerals in Lake Neusiedl

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Lake Neusiedl is located at the Austrian-Hungarian border and of great ecological and economic importance for this region. In view of constantly rising Earth`s atmospheric temperature, atmospheric CO_2 level and associated evaporation rates, there is serious concern about the future development of this lake, particularly in its volume and composition. To counteract a steep drop in the water level, attention has recently been given to artificially discharging water into the lake. However, the impact on its hydrochemical balance could result in unforeseen consequences for its composition and ecology. Therefore, it is necessary to understand the hydrogeochemical cycles of the lake, as well as its carbonate system. Of particular interest is the formation of Ca-Mg carbonate minerals in Lake Neusiedl and potential environmental changes in the catchment area of the Wulka, which is the most important tributary stream of the lake. One lake site and the Wulka including her four main tributary streams were studied based on hydrological and hydrogeochemical data recorded during a spring and summer monitoring campaign. Therefore, the contribution of the individual tributaries to the overall system, as well as the influence of the geologically heterogeneous catchment area and distinct water-rock interaction were analysed and assessed. The tributary streams show a diverse hydrogeochemical composition indicating both silicate and carbonate weathering at distinct degrees, which can be also followed by radiogenic Sr distribution. Moreover, the suspended sediment load was examined using XRD, macrophotography stacking and high-resolution imaging techniques indicating recent Ca-Mg carbonate mineral formation in the water column of the lake. The suspended sediment shows a seasonal variability in the precipitation of low-Mg calcite, high-Mg calcite and protodolomite most likely via precursor mineral phases. Our findings highlight the need of developing sustainable strategies to preserve this vulnerable ecosystem.

SEDEX deposits in the Graz Paleozoic – investigations to the exploration potential with the Arzberg deposit as calibration region

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The sedimentary exhalative (SEDEX) deposits of the Graz Paleozoic (Austroalpine Unit, Eastern Alps) carry raw materials that have been important for basic supply for a long time (Ag, Pb and Zn). Some of the raw materials that are potentially available in these ores (barite, Co, In, Sb and Ge) have been put on the list of critical raw materials by the European Commission. Of the Paleozoic units of the Eastern Alps, these deposits constitute the most important ore district for non-ferrous metals. On a global scale, SEDEX deposits are among the largest non-ferrous metal concentrations, containing > 50 % of the world`s resources for zinc and lead and carrying a number of other important minor elements (for example Co, In, Sb and Ge) in addition to silver. The deposits of the former mining districts in the Graz Paleozoic are well studied, however, the focus was mainly on the ore occurrences themselves providing details on ore mineralogy and chemical composition. A detailed investigation of the spatial extent and composition of wall rock alteration formed during the mineralization process is missing. However, these alterations are an essential tool for exploration of SEDEX mineralizations and are recorded and characterized in this project. The definition and application of proximity indicators from geochemical and mineralogical data can provide evidence of hidden ore occurrences. As a further prospecting method, the investigation of stream and mine waters and their respective sediments in and around a deposit is used. Not only in the case of the Graz Paleozoic such a detailed survey, which considers all indicative measurable geochemical factors, is missing. This investigation is carried out in the Arzberg test area in this project. Arzberg and its surroundings were sites of mining for silver, lead and zinc for about 680 documented years. After several closures and restarts, mining was terminated in 1927. Since then, there has been repeated research work as well as an exploration phase with drilling activity in the 1970s to 1980s. The results of these investigations are to be built upon in this survey. The project MRI_SEDEXPOT, supported by the “Initiative GBA-Forschungspartnerschaften Mineralrohstoffe – MRI”, aims to calibrate and define prospectivity indicators for base and critical metal deposits in the Graz Paleozoic. These could also be transferable to SEDEX deposits in other areas.

Hidden in plain sight: using Atom Probe Tomography to understand the formation of invisible gold deposits in North American, China, and Europe

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Carlin-type gold (CTG) mineralization is one the best studied, yet poorly understood gold mineralization styles in the world. These deposits occur predominantly along NW-SE trends in central Nevada and are characterized by invisible gold thought to be hosted in sulfide minerals (Cline et al., 2005; Gopon et al., 2019). CTG accounts for 9 % of worldwide gold production, with all of it currently coming from five mining districts in northern and central Nevada. The discoveries of new CTG deposits in the Yukon Territory, Canada, southwest China, and Kyrgyzstan as well as the presence of significant CTG-like-gold in already known deposits in Europe will drastically increase the importance of these deposits in the upcoming years. Furthermore, the presence of gold associated high-tech metals in some of these deposits makes this deposit type potentially important for the Green Energy Transition and mineral resource security. Despite the vast resource that CTG deposits entail, surprisingly little is known about their formation mechanisms, fluid source, or even the manner in which the gold is hosted. We know that the gold tends to occur as trace elements within pyrite, which are difficult to study with the “normal” range of geology tools. With the recent application of atom probe tomography to geologic materials we now have the nano-analytical techniques to truly understand these cryptic and globally important deposits. We combine high-resolution electron probe microanalysis (EPMA) and laser ablation inductively coupled mass spectrometry (LA-ICP-MS) with atom probe tomography (APT). Using a select number of examples from North America, Europe, and China we present data that help to constrain how gold is hosted in these deposits, why sulfide minerals make such great hosts for gold and other critical metals, and share insights from atomic scale trace element and isotopic analysis into the formation mechanisms of these deposits.

Applied geophysics in Phase 1 of the Drilling the Ivrea-Verbano zonE (DIVE) project

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The Drilling the Ivrea-Verbano zonE (DIVE) project is an international collaboration partially funded by the International Continental Scientific Drilling Program (ICDP). DIVE has been established to answer long outstanding questions regarding the lower continental crust and the transition into mantle rocks. In DIVE Phase 1, two ca. 1,000 m deep boreholes will be drilled on the edges of Val d'Ossola, Italy, in close proximity to the Insubric Line, at the collision of the Adriatic and Eurasian Plates, where mantle rocks are known to be at their shallowest position. These boreholes are expected to penetrate metasedimentary, gneissic, gabbroic, pyroxenitic and potentially peridotitic rocks, which have highly contrasting physical responses to the overlying valley sediments. At various stages of the DIVE project applied geophysics has or will play an important role in achieving the scientific aims of DIVE. Seismic surveys were conducted in 2019 as part of the site selection and characterisation process, a necessary step in drill planning and a requirement for ICDP funding. More recently in April 2022, a multi-method geophysical campaign was conducted at the DIVE DT-1b drill-site to characterize the near surface, in order to refine the precise borehole position and avoid near surface drilling hazards. Finally, during the drilling phase (late 2022), borehole geophysics will be conducted to provide measurements of physical properties. This borehole geophysical campaign is funded by the FWF within the project "Origins of seismic reflectivity in lower crustal rocks", hosted at Chair of Applied Geophysics, Montanuniversität Leoben. The various applied geophysics programs will be briefly presented and discussed with relation to the practical and scientific objectives of DIVE.

Metallurgic slag-based geopolymer materials in the circular economy

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Metallurgic slag production in Austria reaches values of 2.8 Mio. t/a, from which 736,000 t/a are currently disposed in landfills. In this context the utilization of the latter in mineral-based construction materials exhibit high potential to increase material circularity, as well as to reduce the environmental impact of construction material production. To date, blast furnace slag (BFS) is the only type that is used in ordinary Portland cement-based (OPC) building materials as aggregate and/or supplementary cementitious materials (SCM), or within geopolymer (GP) applications. Other slags have lower hydraulic reactivity than BFS, which limits their application as SCMs in OPC. Additionally, slags frequently contain higher contents of unwanted elements (e.g. heavy metals), potentially raising environmental concerns when directly supplemented in large quantities in OPC applications. This work presents fundamental feasibility studies on the usage of different, so far industrially unexploited, metallurgic slags from Austrian iron and steel production to be used as a binder in GP materials. Various paste and mortar samples were produced with a slag content between 46 and 93 wt.-% (of binder/solid content). Several mixtures reveal good workability and very high compressive and tensile strength development of up to 100 MPa and 10 MPa after 28 days, respectively. Laboratory acid tests (8 weeks of sulfuric acid attack; pHstat = 2) conducted on several of these mortar formulations exhibited significantly improved durability versus conventional OPC-based high-performance concrete according to standard regulations. These results highlight the overall potential of utilizing metallurgic slags to produce green and sustainable GP-based construction materials.

Preliminary geological maps of Quaternary units in Austria 1:500,000 and 1:1,500,000

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Sedimentary and erosional processes acting in the Quaternary significantly affected today´s landscape and morphology of Austria. The Pleistocene glaciers in particular have shaped the striking landscape of the Eastern Alps. So far, geological overview maps of the Geological Survey neglected (with few exceptions like e.g. Vetters, 1933) the sediments and landforms formed during this period. The presented preliminary maps in the scales 1:500,000 and 1:1,500,000 aim to close this gap. The maps were generated using available map sheets in smaller scales (1:50,000, 1:200,000) and no additional field work has been conducted so far. The aim of both maps is to distinguish areas, where erosion or deposition in different stages of the Quaternary prevailed. In the following, the main features visible in the new overview maps are described: First of all, the most obvious observation is that most Quaternary sediments occur in the Northern Alpine foreland and especially outside of Austria. Looking at the end moraines of the last four major glaciations of the Middle to Late Pleistocene (from old to young – Günz, Mindel, Riß und Würm), it is obvious that the Mindel glaciation was the largest compared to the Riß glaciation and especially to the Würm (Last Glacial Maximum). The deposits of large piedmont glaciers occur north of the Alps from Bavaria to the southwestern part of Upper Austria, where some glaciers left glacial sequences of all four major glaciations consisting of terminal moraines linked to proglacial deposits. In contrast, the easternmost glaciers left their traces within the orogenic belt. In the Klagenfurt Basin for example, the extent of the former Drau Glacier tongue during the climax of the Würm glaciation (= Last Glacial maximum) is evident in the map, even though lots of the moraines were eroded close to their formation as obvious by extensive fluvial deposits of nearly the same age (“Niederterrasse”). Extensive, terraced fluvial deposits also occur in the northern foreland north of the piedmont glacier deposits. Between Salzburg und Munich, wide areas are covered by these sediments, whereas to the west of Munich and in Upper Austria, recent rivers incised deeper into Neogene sediments suggesting that these areas have been uplifted since the Pleistocene. Similar evidence occurs in the Styrian Basin, where only terrace bodies indicate deposition during this time. In contrast, the Vienna Basin is characterised by wide, flat areas, where Pleistocene and recent rivers and their alluvial sediments prevail. In this context, the distribution of aeolian sediments (loess) is also remarkable. They only occur outside of the Alps as small bodies on the Bohemian Massif, in the Alpine foreland tracing fluvial sediments (e.g. Weinviertel, Tulln Basin), or covering huge areas in the Vienna Basin and the Hungarian lowlands. The effect of climate warming is illustrated by large rockslides happening since the deglaciation and by the limited amount of recent deposits in comparison with huge amounts of Pleistocene ones. Since the Lateglacial (Gschnitz, Egesen, Little Ice Age stadials), less sediment was delivered due to glacier retreat into the high-up Alpine valleys and an increasing vegetation cover.

Rock typing for reservoir prediction – a frequently misunderstood concept

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Studies of subsurface reservoirs aim to integrate information of various disciplines including geophysics, geology, petrophysics and reservoir engineering. The ideal workflow starts with characterising the reservoir in all its aspects and subsequently constructing tailored static and dynamic models. This workflow is independent of the study purpose, including hydrocarbon production, subsurface storage or geothermal exploitation. And, getting the basics right is a pre-requisite for studying more complex topics related to fracturing, EOR or CO_2 sequestration. Due to the nature of reservoir data, most of the information is concentrated along the wellbores. The much larger area between wells is at best covered by 3D seismics, which can provide reservoir property trends at low vertical resolution. Reservoir performance, in contrary, is dominated by the characteristics of the poorly defined inter-well space. So, high quality subsurface models require ground truth between wells. How to best estimate reservoir properties away from data points? Available tools in interpolation and property modelling include geostatistics and the use of secondary trend data like seismic attributes or facies models to steer property distribution. Good practice is, to first model the property best defined at wells and for which secondary trend data is available. This property usually is reservoir matrix porosity. Other properties are modelled using their dependence on porosity, like a porosity – permeability relation or subsequently a permeability – water saturation relation, as controls. Doing so, secondary trend data for porosity indirectly control all subsequent properties, thus subsurface resources distribution. This procedure fails in case property interrelationships are not unique. A potential solution is to classify reservoir rocks such, that property inferences are unique in each class. A jargon term of suchlike classification is “rock type”, although a unique definition is not established since rock types vary from reservoir to reservoir. An example is a North Sea oil field consisting of chalk spanning the Maastrichtian-Danian stratigraphic boundary. Lithology and porosity change only marginally at the stratigraphic boundary but nanoplankton species size, thus pore geometry changes. In this case, two rock types refer to stratigraphic zones differing, at the reservoir average porosity of 25 %, by a factor of 10 in permeability and a factor of 2 in irreducible water saturation. Another example is a condensate field in the Mediterranean, made up of fossiliferous limestone. Rocks of similar depositional facies show similar permeability but differ in porosity by a factor of 2. These two modelling rock types were found to differ in the amount of micropores but not in the permeability controlling pore throat size. Reservoir models with predictive power honour relationships of properties, particularly in the space between wells. Model construction calls for case specific rock types to be populated separately, in addition to the first property. Consequently, additional secondary trend data for this rock type model is needed. These indirectly control distribution of properties constrained to the rock types. Ideally, rock types are tailored by specialists in an interdisciplinary team – they are essentially human made. This finding contradicts industry trends propagating automatized default workflows and artificial intelligence.

The Austroalpine Schladming Nappe – a key area revealing the pre-Alpine evolution of the Eastern Alps

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Pre-alpine remnants of crystalline basement rocks are known from the Schladming Nappe which belongs to the Silvretta-Seckau Nappe System. These basement rocks are a key to the reconstruction of the Variscan and pre-Variscan history of the Eastern Alps and, thus, deserve further inspection. The Schladming Nappe, mainly consisting of variable paragneisses, also comprises several subsequently overprinted intrusions, now recognized as metagranitoids. For this study, information on these metagranitoids was acquired through whole rock geochemistry and LA-MC-ICP-MS U-Pb zircon dating to gain insight into the magmatic emplacement history and to allow a tectono-metamorphic reconstruction of the history of the Schladming Nappe. We were able to distinguish three intrusive events: (1) a Cambrian event yielding $^{206}Pb/^{238}U$ zircon mean ages between 480 ± 6.4 and 501 ± 7 Ma in the western part of the Schladming Nappe, (2) a Late Devonian/Early Carboniferous event with zircon mean ages between 350 ± 5 Ma and 370 ± 5 Ma in the north and (3) a Permian event with zircon mean ages between 261 ± 3.5 Ma and 263.4 ± 3.5 Ma in the southeastern part of the nappe. The three age groups can be divided by their age, but also due to their position and their whole rock geochemistry. The metagranitoids are peraluminous, with the Cambrian age group being highly evolved and exhibiting higher SiO_2 values compared to the Late Devonian age group. The northern Late Devonian age group contains higher contents of CaO, MgO, FeO, Al_2O_3, Sr and Ba. The northern group can further be subdivided, with a northeastern subgroup depicting a distinct negative Eu-anomaly (EuN/Eu* = 0.44–0.69) and a northwestern subgroup lacking one (EuN/Eu* = 0.82–1.08). The southeastern Permian age group contains high amounts of K_2O, Nb and Y. While the early Variscan metagranitoids can be attributed to an active continental margin, associated with the subduction of Paleotethys, the Late Cambrian to Early Ordovician metagranitoids are potentially connected to a magmatic arc system on the northern Gondwana margin. The southeastern Permian granitoids show a mixture of within plate granite affiliations, syn-collision granite and volcanic arc granite signatures and might be related to post-Variscan lithospheric extension.

The Permo-Mesozoic cover sediments of the Seckau-Schladming nappe system and their provenance – a detrital zircon story

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The metamorphosed Permian to Mesozoic cover sediments of the Austroalpine nappes are a clue to understand the paleogeographical framework of the Eastern Alps. Therefore, the metasedimentary cover rocks of the Schladming Nappe and the Seckau Nappe (Rannach Formation) were sampled and age data were acquired through LA-MC-ICP-MS U-Pb detrital zircon dating. The metasediments are characterized by coarse grained Alpine Verrucano type rocks, metaconglomerates and quartzphyllites to pure quartzites. Within the Rannach Formation, they were sampled along the stratigraphic sequence from the (primary) contact to the pre-Alpine basement to the uppermost exposed parts. The detrital zircons of both nappes exhibit a strong affinity to magmatic origin (over 90 % of the zircons have Th/U above 0.1) and geochronological ages range from Mesoarchean/late Neoarchean to Permian, with most of the ages lying between Middle Ediacarian to Early Permian. The main KDE peaks found in both cover units are Late Carboniferous to Early Permian (c. 290 Ma), Middle to Late Ordovician (c.450 Ma) and early Cambrian (c. 540 Ma). The main differences between the Schladming and Seckau sedimentary cover is visible within the KDE peaks of Late Devonian/early Carboniferous (c. 360 Ma) and Cambrian (c. 490 Ma), which are only found in the Rannach Formation, and middle Carboniferous peaks (c. 330 Ma), only present in the Schladming nappe cover. Distribution of Neoproterozoic ages suggest a common source from the northeastern Gondwana margin. The ages solely found within the Rannach Formation can be accounted for by an internal source, as these ages are known from the crystalline basement of the Seckau nappe. The KDE peaks found in both cover units might be associated with sources within the Alpine realm, e.g., units south of Tauern Window, while the middle Carboniferous ages only found within the Schladming Nappe cover and the Permian peak of both covers seem to be connected to the Central Gneiss of the Tauern Window.

Ein integrativer Überblick über die Grundwasserqualität im Murtal: Von der Quelle bis zur slowenischen Grenze

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61 Standorte, verteilt auf 46 Grundwassermessstellen und 15 Messtellen an der Mur und Zubringer wurden jeweils im Sommer und Herbst 2020 beprobt. Diese 61 Standorte decken die Mur und die begleitenden Aquifere ausgehend von der Quelle im Nationalpark Hohe Tauern auf ca. 2.000 m ü. A. bis hin zur slowenischen Staatsgrenze auf ca. 200 m ü. A. ab. Bei der Messstellenauswahl wurde die Landnutzung (extensive Berglandwirtschaft, intensive Landwirtschaft im Vorland, ländliche und städtische Siedlungs- und Industriegebiete) als wesentlicher Einflussfaktor auf Fluss- und Grundwasser berücksichtigt. Der Fokus der Analysen lag beim Nitrat, bei ausgewählten Spurenschadstoffen zur Abwasserindikation und der Wasserisotopie, sowie mikrobiologischen Messgrößen (B-A-(E) Index). Neben lokalen Effekten wie z.B. den Neubildungsprozessen im Übergang vom Gebirge ins Vorland (Mountain Front Recharge), Mooreinfluss oder den möglichen Einflüssen des ehemaligen Kohlebergbaus bei Fohnsdorf zeigt sich eine durch die Landnutzung bedingte, scheinbare, Höhenabhängigkeit des Nitrats und der Spurenschadstoffe. Die Isotopie zeigt die Einflüsse der Mur auf das Grundwasser, sowie die Auswirkungen der (ehemaligen) Kiesgruben im Vorland. Der B-A-(E) Index zeigt, dass die meisten Grundwässer anthropogen beeinflusst sind, insbesondere die flachen Vorlandaquifere. Diese Arbeit wurde durch die österreichische Akademie der Wissenschaften (ÖAW) im Rahmen der ESS Projekte 2018 (https://www.oeaw.ac.at/ess/ess-projekte-2018/), „Impact of extreme events on the quantity and quality of groundwater in alpine regions – multiple-index application for an integrative hydrogeo-ecologocal assessment (Integrative Groundwater Assessment)" gefördert.

Rise and demise of the Paleo-Danube delta during the late Miocene (Vienna Basin, Austria)

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We present a detailed description of the depositional architecture of the Paleo-Danube delta in the Austrian part of the central Vienna Basin based on the integration of 3D seismic surveys and well-log data. The Paleo-Danube delta formed between c. 11.5–11.3 Ma as part of a 3rd order lowstand of Lake Pannon. The delta deposits are framed within two 4th order flooding surfaces, used as correlation horizons in the seismic interpretations. Morphologically, the delta is divided into a western part with a braided river delta plain and an eastern and southeastern part consisting of five distinct delta lobes, which are defined as Großengersdorf, Aderklaa, Markgrafneusiedl, Matzen and Zistersdorf lobes. Seismic architecture reveals consecutive onlaps of theses lobes, documenting that the lobes developed successively through time. The initial delta progradation was oriented in southern direction, roughly coinciding with the Aderklaa fault system. Subsequent lobes switched into eastern and northeastern directions and finally switched back into southern direction. Simultaneously, the point of origination of the lobes switched towards the northeast with the most prominent shift of 15 km occurring between the Markgrafneusiedl and the Matzen lobes. This channel migration was probably governed by a stepwise activity of the Pirawarth-Steinberg fault system. In total, the delta complex spreads over about 850 km^2. The geometry of the lobes, the steeply inclined clinoforms and the development of large beach ridge fields classify the delta as a river-dominated delta with strong influence of wave reworking, comparable to the modern Danube delta. The switch in geometry, from narrowly elongate of the initial lobe to broad lobate of subsequent lobes, suggests increasing influence of wave activity and a decrease in accommodation space. In-seismic measurements of clinoforms illustrate a drop of the relative lake level of about 80 m during deposition of the lobes. The size of the Paleo-Danube delta was about six times smaller than the Holocene to recent Danube delta in the Black Sea. The pace of delta progradation was distinctly slower and the rate of sediment accumulation was about 70 times smaller, indicating a considerably lower sediment load compared to that of the modern Danube. This observation is in line with the distinctly shorter and substantially smaller drainage system of the Paleo-Danube as compared to the extent of the modern Danube river drainage basin. After about 200 kyr, the Paleo-Danube delta was pushed back into the North Alpine Foreland Basin at around 11.3 Ma due to the strong 3rd order lake level rise of Lake Pannon, which culminated in the maximum extent of Lake Pannon during the middle Pannonian. The results are published in Borzi et al. (2022): Late Miocene Evolution of the Paleo-Danube Delta (Vienna Basin, Austria). – Global and Planetary Change, 103769. https://doi.org/10.1016/j.gloplacha.2022.103769

Integrated stratigraphy of the Vienna Basin – data, concepts, paradigms

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During the last years, several projects have been initiated by OMV to improve the stratigraphic resolution of the Neogene deposits in the Vienna Basin. So far, all attempts to propose an integrated stratigraphy of the basin were hampered by the limited information from few surface outcrops and by the lack of cross-correlations between the major hydrocarbon fields. Within our projects, numerous lithostratigraphic units were validated or newly defined based on well-log and seismic information coupled with new biostratigraphic data from hundreds of core samples. The resulting information was put into an updated chronostratigraphic frame, which is now synthesized in the “Cenozoic Lithostratigraphic Units of Austria (sedimentary successions)”. The new data allowed not only to clearly define sediment thicknesses and to trace major unconformities but revealed also gaps in sedimentation, which so far have been overlooked. In addition, for all lithostratigraphic units, the prevailing paleoenvironments have been evaluated and the paleobathymetry of different parts of the basin was calculated through time by applying a new transfer-function, based on foraminifers. The adapted chronostratigraphy is a major anchor for any calculations of sedimentation rates and thus for interpretations of the subsidence history of the Vienna Basin. Many paradigms, such as the Eggenburgian onset of piggy-back tectonics, the absence of anhydrites of the Badenian Salinity Crisis in the Vienna Basin, and the presence of Pontian strata, have been questioned by the new results. The refined regional chronostratigraphy leads to a critical evaluation of fits and misfits in correlating major stratigraphic boundaries in the Vienna Basin (which in some cases might act as pars pro toto for Central Paratethys stratigraphy) with global climatic events and global sea-level changes. Hence, the newly established scheme will be an important step for distinguishing the influence of global events from regional tectonics.

The oolite of the Venus from Willendorf – microstructure and provenance

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The about 30,000 years old Venus from Willendorf is one of the most iconic artifacts. The enigmatic figurine was found on August 7th 1908 in loess sediments and is assigned to the Gravettian culture. The statuette, stored at the Natural History Museum in Vienna, is 110 mm in height and represents a symbolized adult and faceless female with exaggerated genitalia, pronounced haunches, protruding belly, heavy breasts, and sophisticated headdress or hairdo. The figurine was carved from oolitic limestone and painted red, possibly with ochre, which was almost entirely removed by cleaning at the time of discovery. Interestingly, oolitic limestones do not occur in and around Willendorf. Consequently, various theories about the potential source have been discussed in the literature including Miocene oolites from the Vienna Basin and Jurassic limestones from Stránská Skála (Czech Republic). Based on new micro-computed tomography scans with a resolution of 11.5 µm, we try to trace the origin of the rock. For the first time, small fragments of Oxytomidae bivalves could be detected within the statuette, allowing for a biostratigraphical assignment of the Venus oolite to the Mesozoic. The nuclei of ooids turned out to be mostly dissolved and large limonite concretions are embedded which both now can explain the choice of material by the carver and the appearance of several semi-spherical cavities on the surface of the figurine. Sampling numerous oolite occurrences spanning across about 2500 km from France to the Ukraine, we found a strikingly close match for grain size distribution near Lake Garda in the Southern Alps (Italy). Alternatively, samples from the Donets Basin in Ukraine are very close to the Venus oolite. This might indicate considerable mobility of Gravettian people and long-time transport of artefacts from South to North or from East to West by modern human groups before the Last Glacial Maximum. The results of this study are published in Weber et al. (2022): The microstructure and the origin of the Venus from Willendorf. – Scientific Reports, 12, 2926. https://doi.org/10.1038/s41598-022-06799-z

Analysis of alteration effects of lignite-containing soil samples

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To determine the alteration effects of two lignite-containing soil samples (New Mexico, USA (BH) and North Rhine-Westphalia, Germany (HM)), the organic geochemical composition was analysed before and after an accelerated alteration simulation (continuous storage at T = 30 °C/303 K) over a period of 3 months using Rock-Eval pyrolysis, analyses of total carbon contents (TOC), and GC-MS. In addition, humic acid (HA) fractions were extracted from all samples and analysed for their chemical composition. In order to determine the organic geochemical composition, extracted organic matter was separated first into asphaltenes and maltenes. The maltene fraction was separated by MPLC and HMPLC into aliphatic/aromatic fractions and in low-polarity, medium-polarity NSO compounds and acids. All fractions were analysed with GC-MS. HAs are complex macromolecules, which are unmeasurable with a standard GC-MS method. Therefore, alkaline CuO oxidation with a microwave system as well as the derivatisation of HA samples were carried out prior measuring with GC-MS to characterise compositional fragments of these HA. In addition, qualitative measurements by FT-IR spectrometry were performed on both, the lignite-containing soil samples and the HA samples, for functional groups characterisation. The TOC content of the two lignite-containing soil samples as well as that of the HAs extracted from them decreases over the period of alteration. Over the same period, the proportion of asphaltenes and maltenes increases in all lignite-containing samples. Within the maltene fraction, the percentage increase in mass is greatest within the low-polarity fraction. Rock-Eval pyrolysis results show an increase in the volatile hydrocarbons contained in both samples at the S1 peak. In samples HM and their extracted HAs, the S2 peak (= hydrocarbons generated by thermal cracking) increases over the alteration period. In sample BH, alteration processes lead to a decrease in the S2 peak over the same period of time. Within the isolated HAs, a decrease in the S1 peak and a slight increase in the S2 peak can be detected. The GC-MS investigation shows a comparable alteration behaviour of the samples. Within the respective maltene fractions, there is an increase of identified compounds within the saturated and aromatic fractions as well as in low and medium polar sub-fractions. While in sample BH the amount of identified compounds of the acid fraction decreases, a further increase is also recognisable in sample HM. Within the alkanes, an increase in long-chain alkanes can be seen in both samples, while the proportion of short-chain compounds decreases during alteration. Interestingly, the amount of CuO products of HAs is slightly higher in fresh samples in comparison to the alteration products. This difference is bigger for HM than for BH samples. Slight differences are also visible in the FT-IR spectra of the samples for some functional groups (e.g., CH groups). The study shows a strong age-related change in the composition of the organic components for both samples. Both samples show an increase in non-oxidised or only slightly oxidised organic components due to ageing processes of the matter present. It is conceivable that these arise from highly complex organic macromolecules of the original substances, which are decomposed by oxidation processes of ageing.

An Oligocene to Miocene cooling pulse in the easternmost Alps detected by thermochronology – a result of thrust tectonics and/or deep mantle processes?

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Thermochronology has seen widespread application in the Eastern Alps. Tracking upper crustal cooling has focused mainly on the Tauern Window, the core of the collisional orogen, where exhumation has been most prominent. Further to the east, mostly fission track work is concentrated along fault zones and thermochronometers with lower closure temperatures, such as apatite (U-Th)/He dating, have hardly been applied to higher elements of the nappe pile. Due to the scarcity of the dataset and preferential application of fission track dating uppermost crustal cooling below ca. 80 °C remains undetected. In this contribution, we present new low-T thermochronological ages from the easternmost Eastern Alps from the vicinity of the Vienna basin. We carried out apatite (U-Th)/He dating on clastic units, i.e. Gosau Group, Rhenodanubian Flysch and Lunz Formation sandstone. Additional apatite fission track analysis was performed on a smaller subset of these samples. A compilation of existing as well as new vitrinite reflectance data was used for estimating burial paleotemperatures. These served as criteria for sample selection, as sites with temperatures sufficient to reset at least the apatite (U-Th)/He system (> ca. 80 °C) and potentially the apatite fission track system (> ca. 110 °C) were preferentially targeted. We find reset AHe and subordinately reset AFT ages, that monitor a so far un(der)appreciated phase of prominent cooling between ca. 18 to 25 Ma. For flysch sandstones from the Wienerwald both thermochronometers yield similar ages, implying an exhumation phase, which removed 4–6 km of overburden. Similar results were found for Lunz sandstone samples from the area around Lilienfeld. Apatite (U-Th)/He ages from Gosau sandstones along the western border of the Vienna basin were mostly reset with single grain ages clustering around 20 Ma. Our new results are difficult to reconcile with geodynamic models that imply tectonic quiescence during largescale subsidence and widespread deposition of Augenstein clastics. Interestingly, the sedimentary archive of the eastern part of the Molasse basin records a change in the sedimentation pattern and onset of rapid basin infill at ca. 19 Ma, too. We discuss our findings in the light of postcollisional thrust wedge evolution and potential impact of margin architecture and the Bohemian spur. Slab detachment beneath the Eastern Alps has recently been proposed based on results from the AlpArray initiative. We suggest that the newly detected cooling pulse may constitute the surficial expression of this slab break-off.

Digitale Lernspiele als interaktiver Einstieg in den Geologie-Unterricht

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Digitale Lernspiele ermöglichen es, die zeitlich und räumlich schwer greifbaren geologischen Prozesse anschaulich zu machen und bieten zudem zahlreiche Möglichkeiten zur Interaktion im digitalen Raum. Beginnend von kurzen Animationen bis hin zur virtuellen Realität im 3D-Raum kann die Geologie so auf eine spannende und aktivierende Weise in einen modernen Unterricht einfließen. Im Vortrag werden zwei Beispiel von digitalen Lernspielen zu geologischen Themen für unterschiedliche Zielgruppen vorgestellt: Beispiel 1: „Zwischen Regenwolke und Wasserhahn“ In drei Kapiteln wird das Thema Grundwasser und Wasserversorgung für die 3. Klasse NMS und AHS behandelt. Jedes Kapitel ist im Rahmen von einer Schulstunde selbständig einzeln oder in Gruppen zu bearbeiten. Im Kapitel 1 geht es darum zu erfahren, was mit dem Regen, der auf die Erde fällt, passiert, wie er zu Grundwasser wird, wie Grundwasser fließt und welchen Gefahren es ausgesetzt ist. Das Kapitel 2 befasst sich mit dem Wasser im Gebirge. Wie schaut es in einem Karstgebirge aus? Woher kommt das Quellwasser? Warum leben Höhlenforscher gefährlich, wenn es draußen regnet? Im Kapitel 3 geht es um die Wasserversorgung und es wird gezeigt, was alles passieren muss, damit unser Wasser immer ausreichend und sauber aus dem Wasserhahn rinnt. Quizfragen und kurze Spielphasen zwischendurch lockern auf und helfen, das Erlernte zu festigen. Die Schülerinnen und Schüler werden am Ende mit einer Urkunde belohnt. Beispiel 2: „Nach dem Kohlebergbau“ Das Lernspiel wurde speziell für Schülerinnen und Schüler ab 15 Jahren in aktuellen oder ehemaligen Bergbauregionen entwickelt. Es soll Einblicke in den Bergbau geben und die Umweltprobleme diskutieren, die durch den Bergbau auftreten können. Es zeigt zudem, welche Aufgabe nach der Stilllegung eines Bergwerkes noch übrigbleiben und warum diese als „Ewigkeitsaufgaben“ bezeichnet werden. Die Schülerinnen und Schüler können in drei Kapiteln selbständig erfahren, wie eine Lagerstätte (in diesem Fall Kohle) entstanden ist, wie ein Bergwerk von innen aussieht und was ein Bergmann untertage alles braucht. Es geht aber auch um Grubenwasser, warum es die Umwelt gefährden kann und wie man damit umgeht. Das dritte Kapitel thematisiert, dass ein Bergbau für alle Zeiten seine Spuren hinterlässt und manche Probleme auch nach der Stilllegung noch viele Generationen beschäftigen werden. Die Spielerinnen und Spieler sind häufig im 3D-Raum unterwegs und können sich den Themen interaktiv nähern. Am Ende jedes Kapitels steht ein Quiz, um das Gelernte zu festigen. Parallel zum Spiel führen die Schülerinnen und Schüler ein „Grubenbuch“, in dem die wichtigsten “take home messages“ festgehalten werden. Wer das Spiel erfolgreich absolviert hat, macht ein Selfie in Bergmannskluft.

A green future from a contenious past: gold and critical metals in the historic arsenic mining district Strassegg (Styria)

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The green technology, which is needed to limit the effect of climate change, requires substantial amounts of metals such as Bi, Co, Te, Sb and W, which the EU has termed as critical. A stable supply chain of these crucial raw materials is more urgent than ever, especially in the light of the current geo-political instabilities. For a greater independence of critical metals, the European Union needs to rethink its strategy an encourage the domestic production of these resources. The Strassegg historic Au-Ag-As mining district is located at a high mountain pass to the north of Graz (Styria). Starting in the 15th century these mines were continuously operated for several centuries, and finally ended due to a combination of a poor economic situation and the increasing attention that the harmful work practices were receiving (e.g., As-poisoning). In historic mining districts, such as Strassegg, miners would have mostly been targeting visible minerals and elements such as gold. Little to nothing was known of the ability of sulfide minerals to host significant quantities of gold and therefore was not extracted. Our whole rock chemical analyses show that the tailings piles in Strassegg still contain a significant amount of Au and critical metals, and that much of the gold is contained as a refractory component in arsenopyrite. Further, characterizations of the mine tailing via SEM, EPMA and LA-ICP-MS have shown a remarkable content of As, Sb and gold associated with different sulfide phases. The specific content of critical metals will be assigned to ore mineralization phases and the potential of hosting critical elements will be investigated.

The HIKE European Fault Data Base: The interplay of structured data with Linked Data

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Knowledge of the movement along major fault systems is the key for understanding the tectonic evolution in such a complex environment as Europe. Besides being a typical product of geological mapping and a necessary part of kinematic models, faults are also prominent features defining resources (e.g. minerals, thermal conduits) and/or inducing potential hazard to subsurface drilling, injection and extraction activities (e.g. conventional hydrocarbon extraction in Groningen, Netherlands). Furthermore, the knowledge on faults, their subsurface geometry and deformation history has also increased in complexity, eventually showing the limits of printed maps for adequately representing the current state of knowledge. Therefore, collecting and structuring the available information on faults and presenting it in a harmonized and generally accessible way across national borders is a necessary challenge for geologists and geodata providers. Previous efforts focused on seismogenic fault (e.g., GEM Global Active Faults Database, SHARE European Database of Seismogenic Faults, USGS Quaternary faults database). Here, we present the HIKE European fault database (EFDB), which had the objective to provide a consistent and uniform repository of all types of faults and their characteristics across Europe. In order to capture the variety of geological environments and the highly varying levels of available data, the EFDB combines three different aspects of a fault object: fault geometry, kinematic attributes and a linked semantic vocabulary where non-structured information can be stored. In addition to structured information stored in attribute tables, the EFDB contains a hierarchical classification scheme, which sorts faults and shear zones into groups of local, regional or transregional relevance through a semantic vocabulary of named faults. The vocabulary that has been generated under the principles of Linked Data, which allows storing unstructured information such as geographic description, detailed investigation history, debated theories etc., but also creates a network beyond the actual fault database by including links to other existing fault databases and additional information, e.g. Wikipedia or other semantic vocabularies. We show that a balanced mix of structured information stored in attribute tables and an associated semantic vocabulary provides geologists the opportunity to share complex geodynamic and kinematic information. The European fault database was developed during the Horizon 2020 GeoERA projekt HIKE and contains data from Geological Survey Organizations in Austria (GBA), the Netherlands (TNO), Germany (BGR, LfU, LAGB, LBGR), Belgium (RBINS-GSB), Iceland (ISOR), Denmark (GEUS), Poland (PIG-PIB), Lithuania (LGT), Italy (ISPRA), France (BRGM), Ukraine (GEOINFORM), Portugal (LNEG), Slovenia (GeoZS), Albania (AGS) and 43 the Pannonian Basin Area (MBFSZ). The GeoERA HIKE project has received funding from the European Union's Horizon 2020 research and innovation programme under agreement No. 731166. The HIKE European Fault and the related fault inventory vocabulary is openly accessible via https://geoera.eu/projects/hike10/faultdatabase/.

3D-modelling of the Hochstegen Formation of the western Tauern Window at the Brenner Pass

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The Hochstegen Formation in the western Tauern Window represents the autochthonous sedimentary cover of the external, pre-alpidic European margin. This Jurassic formation transgresses on a lithological highly variable basement of Permo-Triassic trough sediments and partly mylonitic Permo-Carboniferous gneiss cores of the Venediger duplex. The Hochstegen Formation is predominantly composed of the Hochstegen marble and a basal quartzite (Basisquartzit) and underwent up to amphibolite facies metamorphism during the Alpine orogeny. In this study we investigated the nappe stack in general and the Hochstegen Formation in detail including its contact to the overlaying Kaserer Series. The study is based on detailed lithological and structural mapping including several deep drill cores of the exploration campaign for the Brenner Base Tunnel. The results were used to elaborate a 3D model using Petex MOVE. The study aims to improve the knowledge about subsurface structures of the partly karstified Hochstegen marble, which are of high relevance for the Brenner Base Tunnel, especially for hydrogeological questions. We present a new tectonic model, that includes large scale isoclinal folding and internal thrusting of the Hochstegen Formation related to the nappe stacking within the Tauern Window. Between Flatschspitz in the south and Vals valley in the north, the Hochstegen Formation is on the one hand the autochthonous cover of the Central Geiss with transgressive contact to it, and on the other hand is part of the overlying Wolfendorn nappe. We interpret the contact between the Kaserer Series and the top of the Hochstegen Formation to be a ductile tectonic contact, and not a sedimentary one. Therefore, we suggest a Permo-Triassic age for the Kaserer Series and a new tectonic nappe boundary at its base. This leads to a thinning of the Wolfendorn Nappe, which is reduced to a single slice of Hochstegen Formation. During Miocene exhumation of the Tauern Window these older tectonic boundaries were reworked and overprinted by normal faulting along the Brenner Fault and by a set of NE-SW striking brittle sinistral strike slip faults.

Pollen assemblages of subhumid and sclerophyllous plants and intrazonal water plants revealed by SEM pollen analysis of mid-Miocene deposits of Entrischenbrunn (Bavaria, Germany)

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The one-meter-thick intercalated marly sediments of Entrischenbrunn represent an oxbow lake deposition within a braided fluvial system of late Langhian age (middle Miocene). The organic rich upper part of the marls, characterized by the presence of numerous plant macrofossils, have been investigated for palynomorphs with SEM for higher resolution. The palynological results reveal that many typical azonal broad leaved forest elements were present, such as *Carya*, *Fraxinus*, *Liquidambar*, *Tilia*, and unsurprisingly mirror some of the very common macro fossils, such as pollen of *Sporotrapoidites erdtmanii*, *Tricolporopollenites wackersdorfensis* (= *Hemitrapa*, and *Podocarpium*), *Platanus* sp., *Quercus* sps., and *Ulmus* sps. However, the palynoflora as well comprises floral elements not known as macrofossils or rare for this locality; i.e., several aquatic plants (*Callitriche*, *Chenopodium*, *Ludwigia*, *Lycopus/Mentha*, *Decodon* and Lythraceae, gen. indet), and a large portion of more subhumid and partly sclerophyllous plants such as *Celtis* (*C. tournefortii*-type), two *Ephedra* sps., two Mediterranean *Erica* sps, *Diospyros* "*batocana*-type", non-aquatic Poaceae, *Quercus* infrageneric group Ilex/Cyclobalanopsis, Sapoteae (cf. *Mimusops* /*Manilkara*/ *Madhuca*), *Sideroxylon*, *Rehderodendron*, *Royena* "*fischeri*-type", *Ulmus* "*minor*/ *pumila*-type", *Zelkova "abelica*/ *serrata*-type", and *Ziziphus* "*mucronata*-type". The high diversity of "drier subhumid plants" cannot be interpreted easily, consequently we propose three possibilities: 1. The locality had a geographically controlled localized lower precipitation, 2. Deposition in a period of lower precipitation and 3. The overall zonal vegetation consisted as well of several patches of subhumid sclerophyllous vegetation on drier grounds (e.g., pebble and sand bars in a braided system). A combination of all three is also possible.

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Thermodynamic modeling and in situ U-Th-Pb geochronology constrain polymetamorphism and a large Eo-Alpine metamorphic gap between the Koralpe-Wölz and Drauzug-Gurktal nappe systems (Austroalpine Unit, Eastern Alps, Austria)

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In metamorphic units where precise thermobarometric and geochronologic data are ambiguous or lacking, the temporal interpretation of metamorphism and the identification of polymetamorphic histories can be challenging. We present new P-T-t-D data from samples collected in two Austroalpine nappes exposed in the Eastern Alps (NE of Graz, Austria): the structurally upper Schöckel Nappe ("Graz Paleozoic", Drauzug-Gurktal Nappe System) and the structurally lower Waxenegg Nappe (Koralpe-Wölz Nappe System). Although polymetamorphism is previously documented in the Waxenegg Nappe, the timing of metamorphism is poorly resolved and only sparse geochronology exists in the Schöckel Nappe. In phyllites and micaschists of the Schöckel Nappe, phase relations between chloritoid, white mica, chlorite, ilmenite and rutile, Raman spectroscopy on carbonaceous material (RSCM) and thermodynamic modeling allow the reconstruction of the main metamorphic event at ~470 °C–3 kbar. REE-epidote porphyroblasts grew together with the peak assemblage and are often partially replaced by small (< 10 µm) monazite and thorite. Insitu LA-ICPMS U-Th-Pb dating of well-preserved REE-epidote yields a U-Th-Pb isochron date of 261.3 ± 4.2 Ma, which is interpreted as the timing of peak metamorphism during the Permian Event. Published Rb/Sr white mica and biotite ages suggests that the Schöckel Nappe was overprinted at ~350–400 °C during the Eo-Alpine Event before 119 Ma and subsequently cooled below 300 °C at c. 113 Ma. In the underlying Waxenegg Nappe, garnet-bearing mica schist contains monazite up to 500 µm in length that exhibits distinct core-rim chemical zoning. LA-ICPMS U-Pb analyses targeting the monazite cores yield a ^{204}Pb-corrected U-Pb date of 270.1 ± 0.7 Ma (Permian Event) whereas the rims yield a ^{204}Pb-corrected U-Pb date of 92.2 ± 0.3 Ma (Eo-Alpine Event). The P-T conditions for both events are reconstructed using careful documentation of phase relations, RSCM and thermodynamic modeling. Pseudomorphs after staurolite and relics of plagioclase and sillimanite indicate peak conditions of ~560 °C–4 kbar for the Permian Event. Garnet and chloritoid formed during the pressure dominated Eo-Alpine Event at ~540 °C–9 kbar. We provide unequivocal evidence for Permian metamorphism in the Schöckel Nappe, which was hitherto unknown in this part of the Austroalpine Unit. Our results demonstrate that the metamorphic overprint during the Eo-Alpine in this nappe is lower grade than previously proposed. Combining the data from both nappes, the implication is a metamorphic gap of at least 240 °C and 5 kbar at the time of peak Eo-Alpine metamorphism in the higher grade Waxenegg Nappe. This aligns with the existence of a major normal fault between the Drauzug-Gurktal Nappe System and the Koralpe-Wölz Nappe System in the easternmost part of the Austroalpine Unit, which is comparable to similar structures in its central and western parts. Maximal temperature data in each nappe alone without detailed petrological and geochronological investigations could not support this conclusion as the difference in absolute maximum temperature between the two nappes is a feature inherited from the Permian Event that has a value lower than 100 °C.

Art and geology – anthropogenic strata and latent soils of Vienna

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The multidisciplinary project “The Anthropocene Surge – evolution, expansion and depth of Vienna’s urban environment” looks at the anthropogenic grounds of Vienna from a geological, geostatistical, archaeological, and artistic perspective. Data are used from more than 1,200 archaeological excavation sites and the well logs of the Baugrundkataster, ca. 63,000 well cores drilled over the past 190 years (datasets are provided by the Stadtarchäologie Wien, Wien Museum and MA 29 Brückenbau und Grundbau, Stadt Wien). Kira Lappé uses geostatistical methods to make human intervention in Vienna’s ground visible by interpolating the lower boundary of anthropogenic ground, quantifying its volume, and creating digital models. Through this method, the development of anthropogenic accumulations in this city and their expansion are traced in space and time. Well log descriptions allow to quantify and localize new "anthropocene" materials. Owing to Vienna’s history and its local database, Vienna functions as an ideal ground for the purpose of this study. The Viennese geologist Eduard Suess (1831–1914) was the first earth scientist to publish a geological map and description of a city – his hometown Vienna. By witnessing the razing of the old sixteenth-century city fortifications between 1858 and 1864, he recognized what massive layers of earth could be of human origin, and Suess created the term Schuttdecke or “rubble layer” for these geological unit(s). Katrin Hornek creates artistic formats that allow recipients to imagine and, at best, sense the newly forming urban layers. According to the artist, the aim is to give a body to this “difficult-to-access, complex, constantly changing artificial strata of the city.” This spatio-temporal entity emerges in the reception of the multimedia installation Latent Soils, with the individual parts of the case study enabling different approaches. At the center of the artistic part of the project is the video and sound installation “Der Boden von Wien”, which allows the viewer to hear and see all the words that have been used since 1831 in the City of Vienna’s Well Core Cadastre to record the human-modified ground of Vienna. The 87,963 material entries – including errors, variant descriptions, abbreviations, and combinations with punctuation marks – were ranked by frequency and read in an eight-hour session by performer Sabina Holzer. The long list of designations makes the extent of human intervention, its rapid acceleration in recent decades and its materiality tangible. The reshaping of urban ground can be grasped in videos like "Latent Soils", with thousands of images from the city’s archaeological archive fed into the Style Generative Adversarial Network of the platform Runway. This algorithm used deep learning methods to synthesize pictorial elements and thus created possible datasets to come. Endless sets of image streams are opening a space of countless futures to unfold. With Algorithmic forms casted in disturbed soils, Hornek transfers this potential back into analogue space and into the present by materializing digital objects created in the process of synthetic image generation as sculptures. The artist uses as molds accumulations of modified Viennese ground—the very material from which the images have emerged.

Stratigraphy in Web 3.0 – Advantages of a controlled vocabulary for stratigraphic units

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The digital processing of scientific knowledge on geological units and entities can be a challenge. A relational database system quickly becomes complex and poorly performing if poly-hierarchies, synonyms, homonyms, errata, alternative spellings, or content vagueness are to be considered. A more feasible option to address these challenges is to create and use a controlled vocabulary in the form of an online thesaurus. Controlled vocabularies provide the potential to clarify expert knowledge and terminology in the form of thematic vocabulary concepts (terms) at a scientific level and to use them in datasets to code data. By using persistent identifiers instead of labels, which are often impermanent and ambiguous, these concepts are assigned to a URI and can be used to encode data and serve as a unique resource in data visualization tools, for example. In the Thesaurus of the Geological Survey (GBA Thesaurus – https://thesaurus.geolba.ac.at/), concepts from dataset publications on geological units have been processed in such a controlled vocabulary according to the SKOS standard (Simple Knowledge Organization System) for more than ten years now. The GBA Thesaurus results in a knowledge database of bibliographically referenced concepts that have been developed through scientific publications. Within the GBA Thesaurus it is already possible to establish sharp and less sharp associative and (poly)hierarchical relations between different terms and vocabulary schemas. In addition, linking can be made to existing content and information systems on the web, such as e.g. the CGI vocabularies (http://geosciml.org/resource/) e.g. and soon the Lithostratigraphic Lexicon of the German Stratigraphic Society. With the GBA Thesaurus and the linking of concepts, we are thus providing a cornerstone for the cross-border harmonization of geological units. With this use of Linked Data technology, we are already part of the world of the Semantic Web – the Web 3.0.

Digital dissemination of geological information – Recent insights into the geoinformation bubble

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One objective in the work on public sector geoinformation is to publish the geospatial data created by the respective institution digitally. This must be done in such a way that they are easily accessible and available in an interoperable way in accordance with the legal basis. With regard to this processing of geoinformation, there is a rapidly progressing development, also in the field of geosciences. In this area, one increasingly encounters terms such as 3D GIS and BIM, Controlled Vocabulary, Linked (Open) Data, Knowledge Graph, AI, Big Data, Data Cube, Digital Twin and many more. But what are these topics about? To what extent can they be useful for the processing and dissemination of geological information and what are the prerequisites for this? In particular, these technologies should help us to do our work more efficiently. They should offer added value in the generation of new knowledge, especially with regard to the currently relevant challenges in the field of climate change and raw material resilience. Furthermore, the use of these technologies aims to improve the processing, generation, storage and exchange of knowledge. Basic requirements for the use of the technologies mentioned are a stable spatial data infrastructure and machine-readable data. The implementation of internationally agreed standards is also an essential point in order to be able to use knowledge digitally in a sustainable, replicable and interoperable way. A well-known use case in which these basic requirements have already been implemented is the controlled vocabulary of the Geological Survey of Austria (GBA), the GBA Thesaurus (https://thesaurus.geolba.ac.at/). The free availability of this vocabulary to all users and the use of open, accredited standard formats (e.g. RDF, SKOS), enables the applicability of Linked Open Data (LOD) technology. Furthermore, this supports the use of knowledge graphs and the building of knowledge bases. A larger-scale practical implementation in this regard is already planned in an upcoming Coordination and Support Action project “Geological Service for Europe (GSEU)” under the programme Horizon Europe. To ensure that geoscientific data, however well prepared, can be found and accessed at all in the sheer vastness of the internet, it is essential to implement the “FAIR Data Principles”. These have already been taken into account in the GBA Thesaurus and are an important basic element in “TETHYS”, the Research Data Repository (RDR) of the GBA (https://www.tethys.at/). FAIR Data Principles – the acronym stands for Findable, Accessible, Interoperable, Re-usable – are gaining more and more importance. Along with these four marking key concepts, sustainability is very important to make the data a solid base of information and knowledge within the scientific community. It is well understood, that data intended for reuse and networking must be made accessible at a low threshold for both the user and for the machine. To achieve this, validated standards at various levels are indispensable. Using the research data repository of the Geological Survey of Austria „TETHYS“ (www.tethys.at) as an example, we want to show a possible implementation of the FAIR Data principles and their influence in the international digital science network.

Die Klientel der BIUK-Studierenden: einige Querschnittsbetrachtungen

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Viele Studien sind sich darüber einig, dass Geländeexkursionen das anwendungsorientierte, kooperative und selbstgesteuerte Lernen anregen und zusätzlich das Lernklima positiv beeinflussen, weil gezielt mehrere Wahrnehmungs- und Lernkanäle stimuliert werden. Auch ist ein erhöhter didaktischer und mäeutischer Wert im „Be-greifen“ gegründet, der auf mehreren Metaebenen stattfinden kann und damit besonders effektiv ist. Daher sollte in der Ausbildung zukünftiger Lehrerinnen und Lehrer besonderes Augenmerk auf entsprechende Geländelehrveranstaltungen gelegt werden. Doch wie stehen dazu die Studierenden? Haben sie während ihrer schulischen Laufbahn Lehrausgänge miterlebt? Sind diese positiv konnotiert? Liegt ihr Interessensfeld überhaupt in einem Teilgebiet, das außerschulische Lernorte benötigt? Im vergangenen Semester wurden an der Grazer Universität während erdwissenschaftlicher Exkursionen Lehramts-Studierende des Faches Biologie und Umweltkunde (BIUK) dahingehend befragt. Eine detailliertere Darstellung erfolgt im Vortrag, doch seien hier einige markante „Eckpunkte“ angeführt: Auf die Frage, welches Gebiet des „Biologie-Unterrichts“ besonders interessant erscheint, gaben 27 % der Studierenden Humanbiologie, 26 % Zoologie und 15 % Botanik an. Die Erdwissenschaften sind keine signifikante Größe! Das ist auch dem geringen Ausmaß an erdwissenschaftlichen Themen während des gymnasialen Unterrichts geschuldet: 71 % gaben an, dass lediglich 0–2 % des Unterrichts auf entsprechende Inhalte entfielen. Zudem gaben fast 60 % an, dass diese „wenig bis gar nicht interessant“ vermittelt wurden. In der Selbsteinschätzung betreffend ihren Wissensstand für den Eintritt in ein universitäres Studium gaben 47 % an, dass ihr Wissen „mangelhaft“, 42 % meinten sogar, dass dieses „nicht vorhanden“ war. Immerhin sind die Studierenden aber zu 40 % der Meinung, dass Erdwissenschaften für das Verständnis global-vernetzter biologischer Sachverhalte „wichtig“ sind, 3 % meinen, dass sie „sehr wichtig“ sind. Auf die Frage, ob die Befragten eine Exkursion mit Schülerinnen und Schülern organisieren und durchführen würden, gaben 92 % an, dies in ihrer zukünftigen Laufbahn einplanen zu wollen. 98 % der Studierenden sind der Meinung, dass der pädagogische, didaktische und fachliche Mehrwert, der sich aus einer Exkursion ergibt, den anfallenden organisatorischen Mehraufwand (inklusive Vor- und Nachbereitung) überwiegt.

A lithostratigraphic model for the Western Greywacke Zone and the Innsbruck Quarzphyllite Zone (Eastern Alps, Tirol, Salzburg, Austria)

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The Western Greywacke Zone (WGZ) and the Innsbruck Quarzphyllite Zone (IQZ) are informal geologic units exposed in the Eastern Alps of Tirol and Salzburg. Depending on the authors, their definitions are based on lithological, stratigraphic and/or tectonic criteria. Both units are dominated by ductile and brittle deformed greenschist facies siliciclastic rocks, often lacking classical stratigraphic constraints. However, several units well characterized through sedimentology, palaeontology and/or geochronology could already be proposed or formally defined. We developed a stratigraphic model for the WGZ and the IQP on mapsheets Neukirchen am Großvenediger, Kitzbühel and Zell am See, following the North American Stratigraphic Code and combining more than 40 years of geological investigations. First, a tectonic framework was established by identifying Alpine nappe contacts through mapping of deformation gradients, geochronology and petrology. We then formally defined large lithodemic units (complexes or lithodems) in each nappe. Complexes were eventually subdivided in lithodemes and formations in case (even informal) units already existed or if lithic homogeneity justified it. In the process, we reused names of units that are accepted in the regional literature, provided they did not lead to confusion. The WGZ represents the basal part of the Stauffen-Höllengebirge Nappe and its top is defined by a Permian discordance. It is subdivided in four complexes corresponding to Variscan tectonic units: from top to bottom, the Wildseeloder, Hochhördler, Glemmtal and Uttendorf complexes. The Hochhörndler and Uttendorf complexes derive from olisthostromes, which heterogeneity might have been intensified through tectonic processes. The four complexes and their internal subdivisions (e.g. Blasseneck Porphyroid, Löhnersbach Formation, Spielberg Dolomite, …) are already defined in the explanatory notes of the mapsheet Kitzbühel as well as in “The lithostratigraphic units of the Austrian Stratigraphic Chart” and we follow this nomenclature. The IQZ is made up by (at least) three nappes in the following sequence from top to bottom. The Windau Nappe is built by the Glemmtal and Kreuzjoch complexes as well the Kellerjoch Orthogneiss. The Glemmtal Complex differs from its counterpart in the WGZ by a higher degree of metamorphism. The Kreuzjoch Complex contains monotonous metasedimentary rocks without preserved sedimentary structure and rare carbonate and mafic intercalations. The Kellerjoch Orthogneiss derives from a fine to middle-grained metamorphic granite of Lower-Middle Ordovician age and is mostly found between but also within the Kreuzjoch and Glemmtal complexes. The Wildkogel Nappe is made up by the Trattenbach Complex dominated by polyphase phyllonitic micaschist and quartzite. Therein, the Steinkogel Micaschist characterized by the occurrence of Variscan garnet and/or biotite makes a consistent domain. Additional lithologies are Lower-Middle Ordovician granitic/granodioritic orthogneiss, probably Silurian-Devonian calcite and dolomite marble (Gernkogel Lithodeme) and mafic rocks. The Königsleiten Nappe is made up by the Müllachgeier Lithodeme. It corresponds to interlayered micaschist, quartzite and rare metaconglomerate and is characterized by a single tectono-metamorphic imprint and partly preserved sedimentary structures. Detrital zircon geochronology suggests a Permian to Upper Triassic depositional age.

Coupling in situ U-Th-Pb REE-epidote geochronology and thermodynamic forward modelling of main and REE-bearing phases: An example from the Tauern Window

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REE-epidote is a solid solution of epidote-group minerals with rare earth elements plus yttrium that is a common phase of greenschist facies metapelites and a popular target for geochronology. Linking the time information to metamorphic conditions is, however, complicated by the diversity of reactions leading to the formation of REE-epidote as these involve REE- (e.g., monazite, apatite) and Ca-bearing phases (e.g., calcite, plagioclase). In order to model equilibrium assemblages and phase chemistry for both main and REE-bearing phases in metapelites, we compiled a thermodynamic dataset in the system NaKCaFeMgAlSiTiHCOCeYPF by combining data from several sources (Berman, 1988; Pourteau et al., 2014; Spear, 2010; Spear & Pyle, 2010). We tested the database on a graphitic micaschist of the Schwarzkopf Formation collected at the foot of the Hochgamsburg (Fusch valley, Tauern Window). The sample shows relatively simple phase relationships and exhibits evidence for only one metamorphic event. The metamorphic assemblage consists of porphyroblasts of chloritoid, kyanite, REE-epidote and apatite in a matrix of muscovite, paragonite, margarite and quartz. Small rutile, graphite, xenotime and zircon are present as inclusions or in matrix. REE-epidote occurs as euhedral to subhedral, 250–500 µm long grains and displays a microstructural and chemical core-mantle-rim zonation. The core has a patchy or oscillatory BSE pattern and is rich in inclusions of amoeboid quartz and minute graphite, as well as subordinate muscovite, chloritoid, rutile, xenotime and thorite. The mantle is discontinuous (< 60 µm thick), inclusion-free and shows a bright smoother BSE pattern. The rim corresponds to dark and thin discontinuous overgrowths (< 20 µm thick). Core, mantle and rim contain decreasing contents of REE+Th+U in the range 0.5–0.6, 0.4–0.6 and 0.1–0.3 a.p.f.u., respectively. The core and mantle are LREE-rich whereas the rim is HREE+Y-rich. Thirty-one LA-ICPMS analyses of REE-epidote mantle define a 27.5 ± 1.3 Ma U-Th-Pb isochron date (MSWD: 0.69) that is consistent with the conventional Tera-Wasserburg U-Pb date of 27.0 ± 2.3 Ma (MSWD: 0.36). Thermodynamic forward modelling indicates that the observed assemblage chloritoid+kyanite+REE-epidote+muscovite+paragonite+margarite+apatite+rutile+xenotime+quartz is stable together with a graphite buffered COH-fluid in a field centred at 11 kbar – 480 °C, in agreement with results of Raman spectroscopy on carbonaceous material. This field corresponds to the innermost part of the REE-epidote stability domain, in which the Ce-concentration progressively decreases from the margin to the center. Modelling helps with interpreting the zonation of REE-epidote. The core grew from U-Th-rich monazite and most likely lawsonite once REE-epidote became stable. Xenotime inclusions represent products of this reaction. The mantle formed during continued growth further inside the REE-epidote stability domain under increasing temperature. The HREE+Y-rich rim finally grew in an environment depleted in LREE, where xenotime was the main REE-source. The U-Th-Pb isochron date 27.5 ± 1.3 Ma represents the timing of the REE-epidote mantle growth and therefore corresponds to conditions close to peak metamorphism at 11 kbar – 480 °C. These PTt constraints are entirely consistent with the Barrovian metamorphic event that is widespread in the Tauern Window.

Tungsten mineralisation and intrusive rocks at Lienzer Schlossberg, East Tyrol

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Tungsten showings were re-investigated in the Schlossberg area at Lienz within the framework of the GBA Forschungspartnerschaften Mineralrohstoffe (MRI) “W Alps” project. Three types of scheelite mineralization can be distinguished: (1) Scheelite in deformed quartz veins or quartz-rich rocks in the Thurntal Complex. (2) Scheelite in late quartz veins and joints in plutonic rocks of the Edenwald intrusion. (3) Scheelite associated with sulphide-dominated skarn mineralisation. Pyrrhotite rich massive sulphide ores with minor disseminated scheelite are exposed in the former Schlossberg open pit. These skarn ores are associated with thin lenses of marble and calc-silicate rocks within metapelitic hornfels developed in the contact aureole of the km-sized composite Edenwald intrusion. Skarn mineralisation includes a prograde anhydrous high temperature stage with grossular, vesuvianite, diopside-hedenbergite, wollastonite, plagioclase and accessory scheelite and a retrograde stage with hydrous low temperature phases. In the latter, actinolite, biotite, epidote, quartz and scheelite are associated with pyrrhotite and chalcopyrite and late calcite. The skarn mineralisation shows similarities to reduced, magmatic tungsten skarns. The Edenwald intrusion consists of diorites, tonalites, granodiorites and granites and belongs to the Periadriatic intrusions of Oligocene age. The igneous rocks are magnesian, calc-alkalic and span metaluminous to peraluminous compositions. Mafic micro-enclaves containing orthopyroxene, clinopyroxene and plagioclase are preserved in the darker varieties and may indicate involvement of mantle-derived melts. Diorite and tonalite formed during the main magmatic stage. Increase in water content of the melt is indicated by crystallization of biotite and hornblende. Pyroxene in the mafic micro-enclaves was transformed into cummingtonite and actinolite/hornblende during this stage. The third magmatic stage includes strongly fractioned, porphyritic granodioritic to granitic rocks that were mainly emplaced as dykes. In contrast to petrographically and chemically similar intrusions (e.g., Rieserferner) the Edenwald intrusion is enriched in tungsten due to (post-) magmatic hydrothermal processes making it unique among the Periadriatic intrusions.

Lithostratigraphy and lithodemy in metasedimentary rocks of the Austroalpine – New insights from the Stangalm-Brenner Mesozoics (Ötztal-Bundschuh Nappe System, Austria)

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The classification of lithostratigraphic and lithodemic units is a fundamental task in the characterisation of lithologically mixed and/or structurally complicated rock assemblages of intrusive igneous, metamorphic or “mixed” nonstratiform rocks, obligatory for work in map legends and databases at the Geological Survey. Several concepts, such as the “North American Stratigraphic Code (NASC)” proposed by the North American Commission on Stratigraphic Nomenclature (2005) and the “British Geological Survey Rock Unit Classification System” (BRUCS; 2021) provided guidelines and naming conventions. The NASC introduced the term lithodemic unit for intrusive, penetratively deformed, and/or highly metamorphosed rocks, which have lost their primary structure of stratification and position within a stratified sequence through metamorphism or tectonic processes. According to the NASC, lithodemes are distinguished and delimited based on rock characteristics. Contrary to lithostratigraphic units, a lithodemic unit is generally non-stratiform (i.e. it does not conform to the Law of Superposition). The BRUCS-classification bases on the genesis of the rocks and introduces a hierarchical system of classification that corresponds to lithostratigraphic ranks. Non-stratiform units are subdivided into 1) intrusions; 2) tectonometamorphic units; 3) mixed-class units. Partly mentioned in former concepts is the immiscibility of definitions for tectonic and stratigraphic units respectively. However, regarding nomenclature and/or hierarchical classification, these concepts still leave room for discussion, especially when the available data is incomplete or the metamorphic/tectonic overprint is gradually increasing. Further complications arise if such a geological unit is non-contiguous and scattered over a wide area. Where to define the boundary between non-metamorphic and metamorphic rocks? It useful to mix lithostratigraphic and lithodemic terminology expressing the controversity respectively complexity of such a challenge? The Permo-Mesozoic cover of the Ötztal-Bundschuh Nappe System represents a prime example to discuss the differences and applicability of these lithodemic classification systems. The well-known metasedimentary sequences occur East (Stangalm Mesozoic s.l.) and West (Brenner Mesozoic) of the Tauern Window. Both, the Stangalm and the Brenner Mesozoic show an upright section with a southeastward increasing temperature gradient. Fossil-bearing units were overprinted during low-grade (~400 °C) and homogenously obliterated units during high-grade (> 500 °C) metamorphic conditions. While the Brenner Mesozoic is traditionally defined based on lithostratigraphic criteria, recent mapping in the Stangalm Mesozoic provided a lithodemic classification (Iglseder et al., 2019). Highly deformed rocks of the Allgäu-Ruhpolding-Ammergau Formations occur at the structural top of both metasedimentary sequences (Metamorpher Kalkkomplex/Brenner Mesozoic and Leckenschober Lithodeme/Stangalm Mesozoic s.l.) and underline the parallelism of the two Mesozoic cover sequences. Altogether, to allow for the amalgamation of the Mesozoic cover of the Ötztal-Bundschuh Nappe System East and West of the Tauern Window, we propose the term Brenner–Stangalm Complex.

U/Pb zircon ages on tuff in the Aflenz Basin (Styria/ Austria) – Evidence for Middle Miocene widespread volcanic deposits

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Deposits of Miocene volcanic eruptions are widespread all over Central-Eastern Europe. In Austria, occurrences of tuff are found in the Bohemian Massif as well as in the Styrian Basin. Occurrences of special interest have been described in the Fohnsdorf (Ingering Formation) and Lavanttal (Mühldorf Formation) extensional basins, which formed during eastward extrusion of the Eastern Alps. In the course of the mapping project GK102 Aflenz Kurort, a new volcaniclastic deposit has been discovered within the Sulzgraben Member. It is located in the southwestern part of the NE-SW-striking pull-apart Aflenz Basin. Within a 5 m thick detailed profile of different sedimentary layers, two layers of tuff were identified and sampled (WGS84 5262978N/516545E). They were partly rearranged during creep and soil flow processes. The lower part of the profile is built by 1.3 m thick ochre-grey white mica-rich clay and silt with angular local detritus (quartzite). It is followed by a conspicuous 20 cm thick layer with rounded altered greenish tuff components (SAMP1). To the top, the 90 cm of reworked tuff material is overlain by 1.3 m fresh white lapilli and biotite-rich tuff (SAMP2+3) with plant fossils of leaves. The top part of the profile is formed by 30 cm weathered tuff, 30 cm grey-brown clay with plant fossils and detrital white mica and 70 cm of well-rounded silt-sand-gravel with concretions and plant remains. The top tuff shows a mineral assemblage of quartz, feldspar, biotite, glass shards. In thin section, the tuff has a fine-grained matrix with xenocrysts of feldspar and biotite as well as accessory apatite and zircon. A special feature are accretionary lapilli with a dimension up to 2.5 mm, which are characteristic for aerial transported volcanic ash. Bulk rock geochemistry of three tuff samples from the top parts yields a rhyolitic composition with a high silica content of 75 % and a low sodic and potassium content. They show consistent chondrite normalized trace element patterns characterized by slightly decreasing LREE concentrations, a marked Eu anomaly (EuN/Eu*: 0.34–0.39) and almost flat HREE. In addition, high Ba (> 1,000 ppm) and Zr (> 100 ppm) as well as Hf concentrations higher than 3.5 ppm are observed. Zircons were separated from three samples collected along an upright profile and dated with U-Pb LAMCICPMS. The lower greenish tuff in the substratum part (SAMP1) yielded an age of 14.7 ± 0.1 Ma. The two samples of the white pure upper tuff (SAMP2+3) yielded ages around 14.1 ± 0.2 Ma. These age data in combination with geochemistry suggest an ash source from the Tibolddaróc (U-Pb LAICPMS zircon age: 14.7 ± 0.2 Ma) and Harsány (U-Pb LA-ICPMS zircon age: 14.3 ± 0.2 Ma, EuN/Eu*: 0.3–0.4) volcanic events in the Bükkalja Volcanic Field (Hungary) for the lower and upper tuff, respectively. They also provide evidence for widespread volcaniclastic deposits from these sources up to Austria.

An adapted tectonic model for the "Central and Eastern Greywacke Zone" – new geochronological and RSCM-data (Styria/Austria)

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The tectonic nomenclature of the Greywacke Zone (GWZ) and its neighbouring "(Quartz-)Phyllite Zones" has often been a matter of debate. Recently, a new tectonic model for the Western GWZ and the Innsbruck Quartzphyllite Zone has been proposed with the splitting of these zones into Königsleiten-, Wildkogel-, Windau-, Stauffen-Höllengebirge nappes (Huet et al., 2019). We here present new geochronological and Raman Spectroscopy of Carbonaceous Materials (RSCM) data and build up a new tectonic model for the Central (C) and Eastern (E) GWZ. Overall, the E-GWZ is tectonically in a hanging wall position with respect to nappes of the Silvretta-Seckau Nappe System and overlain by cover nappes of the Tirolic-Noric Nappe System. Each tectonic element of the E-GWZ is formed by Palaeozoic basement units with a Permo-Mesozoic cover. In present day models, the Veitsch-Silbersberg Nappe-System with slices of the Kaintaleck Metamorphic Complex as substratum is overlain by the Noric Nappe of the Tirolic-Noric Nappe System. In the E-GWZ new RSCM data show maximum temperature between 360 and 535 °C for the Veitsch and Silbersberg nappes. This range is assigned to the Eoalpine Event based on metamorphism in the cover and the cooling ages in the footwall parts. The maximum temperature recorded in the Noric Nappe is mostly 300–350 °C with temperatures between 240–280 °C in its upper parts close to its Permo-Mesozoic cover. The maximum temperature in the investigated parts of the Juvavic Nappe System ranges around 290–315 °C. The situation in the C-GWZ between the towns Schladming and Rottenmann differs from those identified in the East. In the course of mapping around the town Gröbming, new geochronological and RSCM data show that existing hypotheses needs to be revised. The Öblarn Nappe is a newly defined tectonic unit that includes mainly the Ennstal Phyllite Zone and rocks between the villages Irdning and Oppenberg, hitherto assigned to the Noric Nappe. It is underlain by the Donnersbach Nappe (Koralpe-Wölz Nappe System) and overlain by the Veitsch Nappe. It is interpreted as a basement unit belonging to the Tirolic-Noric Nappe System. RSCM data indicate maximum temperatures between 490 and 565 °C with higher temperatures towards the structural lower part in the south. In combination with U/Pb ages on allanite, this peak temperature is interpreted as a result of combined Permian and early Late Cretaceous (see Stumpf et al., this volume). Detrital zircons dated with U/Pb in metasediments yield ages around 550 Ma and ~625 Ma for the youngest populations. In the hanging wall (around Gröbming) graphitic phyllite, metatuff and Devonian marble, assigned to the Noric Nappe, show maximum temperatures between 455–480 °C and 425–430 °C for the uppermost parts. These temperatures are much higher than those for the Noric Nappe in the E-GWZ and fit better to conditions at the basis of the Stauffen-Höllengebirge Nappe in the W-GWZ. An Ar-Ar muscovite age from the latter unit, determined from a sample collected near the village Filzmoos points to Early Cretaceous cooling. The Mandling Nappe as a cover nappe of the Tirolic-Noric Nappe System shows Tmax conditions around 285–325 °C.

Organic geochemical characterization of Miocene shale in Lower the Kutai Basin, East Kalimantan, Indonesia

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The Lower Kutai Basin is a Cenozoic basin which underlies the region surrounding the recent Mahakam Delta, on the East coast of Kalimantan, Indonesia. A geochemical screening was performed to determine source rock potential of the section in the Lower Kutai Basin. Thirteen of the samples are shales with minimum TOC value of 1.16 % at 1,270 m and maximum TOC value of 5.32 % at 1,200 m. The average TOC of the shales is 2.50 %, which indicates a good source rock potential. This is further supported by the potential yield data which show more than 1 mg/g yield for all the samples. The hydrogen of the shales suggest that they are gas prone, except one sample of carbonaceous shales which shows exceptionally high HI value 450 indicating oil prone source rock. Kerogen typing and elemental analyses on shales indicate mostly type III kerogen with some indications of oxidation and reworking contained in the samples. The dominant maceral is vitrinite, and only rare trace liptinite occur in the samples. All of the organic matter in the samples are inferred to be coming from terrestrial plants associated with mangrove swamp environment. Oil production index were relatively high (up to 0.28) above the 1,890 m fault, which were most likely caused by migrated oils. Below the fault, which was in the shaly interval, the OPI dropped to 0.1 and no oil shows were found. The vitrinite reflectance of the shallowest sample is 0.64 % at 1,200 m, and the reflectance rises gradually downsection to reach 0.70 % at 1,280 m. Below this depth, the reflectance values remain approximately constant over the interval 2,016 to 2,213 m, suggesting the presence of a thrust fault. Given the fact that the maturity of the samples is about the same on both sides of the fault, it seems that the 1,890 m fault has been acting as a conduit for migrating hydrocarbons up to the hanging wall from deeper mature source rock to the East (Nilam Syncline).

3D Ground Model of Vienna: from geological concept to geotechnical application

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The City of Vienna Administration has the largest collection of geodata in Austria, the so called „Wiener Baugrundkataster“. It contains more than 66.000 borehole logs, lots of them including various field and laboratory test results. This archive is mainly used for geological and geotechnical consulting in context with public and private building projects. The development of geological and geotechnical 3D models based on this geodata collection became a significant tool for design, construction and maintenance of public infrastructure projects such as metro lines. After local applications (metro line U1 since 2012), a first larger scale model was established for the metro lines U2 & U5, which cross the city of Vienna (starting 2015). Based on an initial geological model, a geotechnical model was established following the standard “ÖGG-Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation”, which leads to the definition of ”geotechnical ground types”. To represent the new classification system describing the specific mechanical properties, the geometry of the geological model had to be adjusted by combining and further subdividing existing geological units. The geological model was subsequently extended in several phases so that it covers at the moment half of the city surface and of the available boreholes of at least 10 meters depth (referred to as the “city model”). Especially the quaternary sediments where differentiated and classified according to lithological and (litho)stratigrafical criteria. Additionally, the basement surface of the anthropogenic layer of the city center, which has been modelled within the project “The Anthropocene Surge”, has been implemented. In this contribution, the geological 3D model will be presented with the focus on quaternary sediments as well as the derived geotechnical model of the metro lines in Vienna’s city center. Beginning with the collection of factual data like borehole logs, their interpretation and definition of modelled layers and volumes will be presented, including the base surface of the Anthropocene. Finally, the derived geotechnical model of the subway project and its application for planning and prognosis during tunnelling works will be shown in 3D views and sections.

Festgesteinsseismik in Metamorphiten

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Im Rahmen der geologischen Beschreibung der Magnesitlagerstätte in der Breitenau am Hochlantsch wurden bereits existierende reflexionsseismische Daten interpretiert. Die vorhandenen seismischen Daten wurden im Zuge dieses Projekts mit neuen Auswertealgorithmen, die dem Stand der Technik entsprechen, neubearbeitet (Reprocessing). Durch die Implementierung von neuen, weiter ausgereiften mathematischen Algorithmen und der Anwendung von auf die Fragestellung konzipierten Workflows konnte die Qualität und der Fokus der reflexionsseismischen Profile wesentlich optimiert werden. Dadurch werden vor allem die für die Interpretation wichtigen Strukturen hervorgehoben. Die seismischen Rohdaten der betreffenden Seismikprofile wurden im Jahr 2005 und im Jahr 2008 akquiriert und anschließend auch erstbearbeitet. Die Ergebnisse nach einer Neubearbeitung zeichnen sich im Vergleich zu dieser Erstbearbeitung durch ein deutlich größeres Signal/Rausch Verhältnis aus. Ferner konnten bei sämtlichen Profilen die geologischen Strukturen weit klarer und schärfer abgebildet werden als bei der ursprünglichen Bearbeitung. Neben standardisierten Bearbeitungsabläufen wurden die Daten zusätzlich auch einer sogenannten „Finite Differenzen-Shot" – Tiefenmigration (Pre-Stack Depth Migration) unterzogen. Mit dieser Methode erhält man direkt Seismikprofile in Tiefendomäne, so dass die Tiefenwerte direkt den Tiefen unter Geländeoberkante entsprechen.

A thermokarst-related debris flow event at an active rock glacier in the Ötztal Alps (Tyrol, Austria)

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On 13 August 2019, a debris flow eroded the front of an active rock glacier and dammed the main river of Radurschl Valley (Ötztal Alps, Austria). Failure initiated in ice-cemented debris, in response to the outburst of an upstream meltwater lake through newly developed thermokarst channels that transferred substantial amounts of water to the rock glacier front. Analyzing a set of potentially destabilizing factors indicates that permafrost degradation and rapid thermokarst evolution within the rock glacier initiated the sequence of cascading events, comprising lake outburst, slope failure, debris flow development, and river blockage. The critical combination of topographical and sedimentological disposition at the rock glacier front, a high-energy environment favoring permafrost degradation, as well as climate and weather patterns promoting melting processes facilitated the initiation and development of the process chain. Identification and evaluation of these factors demonstrates the potential of rapid thermokarst evolution to induce highly hazardous situations at short time scales and highlights the need to account for permafrost degradation in debris flow hazard assessment studies in periglacial, mountainous environments.

Metamorphic evolution and geochronology of Variscan remnants in the Eastern Alps: the crystalline “Schollen” in the Greywacke Zone

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The Eastern Greywacke Zone is composed of three Alpine nappes. From bottom to top these are the Veitsch nappe (Early Carboniferous to Permian molasse), the Silbersberg nappe with the crystalline “schollen” such as the Kaintaleck Metamorphic Complex and Permian phyllites as cover, and the Noric nappe (mainly Ordovician to Devonian shelf sediments and Permian cover). All units experienced early Alpine lower greenschist facies metamorphism. Ductile shear zones which developed during the Alpine nappe stack building are responsible for the emplacement of the Kaintaleck Complex as lens-shaped bodies of 10–100 m thickness that stretch roughly West to East close to the base of the Noric nappe within the Eastern Greywacke Zone. The westernmost outcrop is located near Kalwang in Upper Styria, the easternmost exposure near Gloggnitz in Lower Austria. Lithologically, the Kaintaleck Complex is represented by a mafic suite, composed of amphibolite, garnet-amphibolite, greenschist and serpentinite, and a felsic suite that consists mostly of mica-schist (some of them garnet-bearing) and gneiss. The felsic units may derive from a former continent, whereas the mafic units represent most likely a former ocean. This work tries to determine the P-T-t path of the Kaintaleck Complex by applying U-Th/Pb dating and application of geothermobarometric/petrological techniques. Based on whole rock geochemistry, amphibolites and garnet-amphibolites from the localities of Prieselbauer and Frauenberg in the area of Bruck/Mur and Kapfenberg, as well as amphibolites from Unteraich and Oberdorf represent tholeiitic basalts with either a T-MORB or E-MORB affinity. Samples from the localities of Stübminggraben and Utschgraben have a N-MORB affinity. However, greenschists from the locality of Kalwang show a calc-alkaline differentiation trend and their trace element and rare-earth element composition indicate a continental arc affinity. The garnet-amphibolites show distinct plagioclase-epidote-rich symplectitic coronas, which are indicative of pressure relief from possibly eclogite-facies metamorphic conditions. First P-T estimations from geothermobarometric calculations yield about 515 °C and 10,2 kbar for the felsic suite, and 600 °C and minimum pressures of 12 kbar for the mafic suite. EPMA monazite dating of two garnet-mica-schists from the locality of Prieselbauer revealed a Variscan age of metamorphism with a mean age of 350.7 ± 4.1 Ma. The monazite grains in these samples are partly replaced by an apatite-allanite-corona, indicative of Alpine lower grade metamorphic overprint.

Who is who in the glacial forefield: a macro fabric-based classification of glacial landforms

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Modern day glaciated areas pose as a sandbox model for the description and interpretation of glacigenic landforms, where cause and effect are well constrained and understood. The description of glacigenic landforms- or features are usually based on the lithofacies (e.g. diamicton, graded sand, etc.) or on sedimentological processes (e.g. meltout till, push moraine). Certainly, this procedure is well established and suitable when dealing with recent landforms. When it comes to ancient glacially associated deposits or former glaciated areas that are isolated or the general context is vague, interpretation can be difficult or ambiguous. Apart from lithofacies and sedimentological properties, the arrangement and orientation of clasts and glacial debris can be used to classify distinct morphotypes that occur in a glacial setting. For this purpose, we studied ice parallel-, orthogonal- and joint landforms as well as amalgamated deposits in the proximity and direct icecontact of the retreating Gepatsch glacier in Tyrol that were analyzed according to their clast macro fabric. Based on the spatial distribution and orientation of clasts that are extracted from virtual outcrop models, UAV surveys and classical fieldwork approaches, the analyzed features differ significantly according to their fabric patterns and allow a classification supporting the existing terminology that helps to provide an alternative for the understanding of glacigenic landforms.

Preliminary study of copper(II) ions removal from wastewater using solid residue obtained by co-pyrolysis of lignite and high density polyethylene mixture

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In the last decade, much attention has been given to thermal treatment (co-pyrolysis) of coal/plastic blends. The hydrocarbon plastic materials, (e.g. polyethylene and polypropylene), which production rapidly increases, should be recycled. They can be the source of hydrogen during the pyrolysis of hydrogen-depleted natural products such as coal and biomass, resulting in a balance of carbon and hydrogen contents and giving the opportunity to certain advantages of the co-pyrolysis process. The composition and quality of liquid and gaseous co-pyrolysis products were evaluated, whereas possible utilization of solid co-pyrolysis product was less investigated. In this study the solid residue obtained by the co-pyrolysis of low quality, mineral-rich lignite taken from the Kostolac Basin, Serbia (45.36 % of ash; 33.42 % of total organic carbon; net calorific value of 9.5 MJ/kg) and high density polyethylene, HDPE (mass ratio, 1:1) at 500 °C was tested as a sorbent for Cu^{2+} ions, considering that as a coaly-based material, simultaneously enriched in clays, it may have good adsorption properties. Sorption experiments were performed using 0.5 g of solid co-pyrolysis lignite/HDPE product, as sorbent which was treated with 5 cm^3 of model solutions containing ~200 times higher concentration of Cu^{2+} ions (242.60 mg/dm^3), in relationship to its maximal allowed content in surface water of bad quality. Model solutions were prepared using corresponding nitrates dissolved in distilled water. Two model solutions were prepared. The first model solution contained individual Cu^{2+} ions, whereas the second one contained a mixture of Cu^{2+}, Pb^{2+}, Co^{2+} and Cd^{2+} ions. Concentration of each ion in the latter was also ~200 times higher than its maximal allowed content in surface water of bad quality. The experiments were carried out in cuvettes by ultrasonication (30 minutes) under ambient conditions, followed by centrifugation (3,000 rpm, 10 minutes) to separate liquid (supernatant) and solid phases. Treatment with distilled water was used as a blank. Concentrations of heavy metal ions in initial model solutions and supernatants obtained after sorption experiments were measured using inductively coupled plasma – optical emission spectrometry. The obtained results indicated very efficient sorption of Cu^{2+} ions from its individual model solution, attaining 99.96 %. The efficiency of Cu^{2+} ions sorption was also high (99.95 %) from model solution, which contained mixture of metal ions. It is important to mention that sorption of other metal ions from model solution mixture was also effective (99.99 %, 80.70 % and 71.04 % for Pb^2, Cd^{2+} and Co^{2+}, respectively). The solid residue obtained by the co-pyrolysis of lignite and HDPE showed better efficiency for Cu^{2+} removal from model waste water than polymer enhanced ultrafiltration, ferric/limestone treatment, sorption by paddy straw, papaya leaf powder and secondary strontium residue, as well as treatment by sand-chemically carbonized rubber wood sawdust column, although our model solution had higher concentration of Cu^{2+} ions (242.60 mg/dm^3) than those used in comparing experiments (up to 160 mg/dm^3). Furthermore, sorption capacity for Cu^{2+} ion remained high in the presence of other heavy metal ions. Therefore, the preliminary results showed promising sorption properties of solid residue obtained by the co-pyrolysis of lignite and HDPE against Cu^{2+}, but also possibly for other heavy metals, particularly, Pb^{2+} ions.

Identification of recharge components and unknown stresses in alluvial aquifers using time series modelling

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Alluvial aquifers provide about one half of Austria's drinking water and even larger portions in many countries around the world. To assess how climate change or direct human impacts, such as groundwater abstraction or hydraulic construction, potentially affect the storage and discharge of groundwater in these settings, sound understanding of the drivers of groundwater level changes is required. This work thus aims to (1) identify different recharge components and other hydrological stresses that affect groundwater levels at a given location and (2) assess their relative contribution to the observed groundwater level fluctuations. To this end, we employed the time series model Pastas (Collenteur et al., Groundwater, 2019), which is available as a Python package at http://www.github.com/pastas/pastas. This model uses pre-defined impulse response functions to represent the impact of individual stresses on groundwater levels. The model was applied to observation wells of the existing state hydrographic monitoring net in the Grazer Feld aquifer, an alluvial aquifer located in the Mur valley after its transition into the Styrian Basin. The northern part of the aquifer lies within the urban area of the city of Graz, while agricultural land use dominates in the southern part. The model calibration resulted in acceptable fits to the data of 128 from the 146 observation wells used for this study. The calibration results suggest that, in addition to recharge from precipitation, for most of the observation wells the river is a relevant driver of groundwater level fluctuations. The groundwater-level time series of about one third of the observation wells appear to be affected by additional stresses. In most of these cases, a good model fit is obtained by assuming a step in the groundwater levels at a distinct time, for example as a result of hydraulic constructions in the river Mur. The unacceptable model fits obtained for 18 observation wells suggest that groundwater levels at these locations are affected by additional drivers that need further investigation.

Der Felssturz von Pürgg – vom Ereignis bis zur Sicherung

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Im November 2017 und Jänner 2018 ereigneten sich im Bereich der Marktgemeinde Stainach-Pürgg im Bezirk Liezen zwei Felssturzereignisse größeren Ausmaßes. Aus der nördlich hinter dem Ortsteil Pürgg ca. 180 m hoch aufragenden Pürgger-Wand, lösten sich etwa 2.500 m³ große Felstürme, welche eine Waldfläche von rund 40.000 m² nahezu „rodeten“. Gedämpft und abgebremst durch den vorhandenen Baumbestand, erreichten einzelne Blöcke das nördliche Siedlungsgebiet sowie Bereiche der Freizeitanlagen. Geologisch gesehen, besteht die Felswand aus Tressensteinkalken, die nach Schmid et al. (2003) zur Dachsteindecke der Nördliche Kalkalpen gehören. Die Kalke aus dem Oberjura sind massig bis gebankt und stark zerklüftet und werden im Bereich der Topfläche vom nordfallenden Basiskonglomerat der Gosau-Gruppe (Kreuzgraben Formation) überlagert. Im Liegenden, unterhalb der exponierten Felswand, stehen die Kalkmergel der Allgäuschichten an. Im Zuge der ersten Erhebungen, nach dem Ereignis am 12. November 2017, durch den diensthabenden geologischen Amtssachverständigen konnten weitere abgelöste Bereiche an einem Felsturm festgestellt werden. Basierend auf diesen Beobachtungen wurde als Erstmaßnahme von der zuständigen Behörde ein Betretungsverbot für den nördlichen Siedlungsbereich verordnet und in der Natur ersichtlich gemacht. Am 10. Jänner 2018 kam es schließlich zum Herausbrechen des aufgelockerten Felsturmes, dessen Gesteinsfragmente bis zum Freibad und der Tennisanlage gelangten. Infolgedessen wurde das Areal des Betretungsverbotes vergrößert und zum langfristigen Schutz des nördlichen Siedlungsbereiches ein Steinschlagschutzdamm mit einem Fallboden errichtet. Die Dimensionierung des Schutzbauwerkes konnte mit Unterstützung umfangreicher Steinschlagsimulationsanalysen der Wildbach- und Lawinenverbauung umgesetzt werden. Nach Einrichtung eines Monitoringsystems bestehend aus Fissurometern und einem Autotheodolit, erfolgten im September 2018 nach täglicher Überprüfung der Felswand und anschließender Freigabe, die Rodungs- und Erdbauarbeiten. Die Sicherungsarbeiten wurden fortlaufend von der Landesgeologie in der Abteilung 15 begleitet und begutachtet. Mit Juni 2019 wurde der 150 m lange und 7 m hohe Steinschlagschutzdamm mitsamt Fallboden fertiggestellt. Aufgrund dessen, dass keine relevanten Bewegungen an den Messpunkten festgestellt wurden, wurde das Monitoringsystem im Juni 2020, nach einer etwa 2-jährigen Beobachtungsperiode, eingestellt.

An Introduction to the UNESCO International Geosciences Program IGCP 732 LANGUAGE of the Anthropocene

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The UNESCO IUGS IGCP 732 project LANGUAGE of the Anthropocene (Lessons in anthropogenic impact: a knowledge network of geological signals to unite and assess global evidence of the Anthropocene), Present and future Geology – the global scale evidence of the Anthropocene was granted as a new UNESCO IUGS IGCP project in spring 2021 and will run for 5 years. IGCP projects intend to bring scientists together for workshops, field trips and scientific exchange and to enable international cooperation in the geosciences, especially with the contributions of scientists from developing and less developed countries. The Anthropocene, which has yet to be defined, establishes a powerful concept associated with unprecedented global change and the anthropogenic predominance of the Earth System. Recognizing and managing this novel situation in a sustainable way requires a planetary network and accompanying knowledge framework, therefore, IGCP 732 aims to engage new ideas and networks in the development of the Anthropocene concept. The major tasks are to unite and assess global evidence of the Anthropocene and to establish the Anthropocene as a fertile framework for future geosciences. This will be achieved by 1) developing a network of expertise and project partners globally; 2) designing and running workshops in developing countries; and 3) designing and collating an open database of existing information and expertise on the Anthropocene. In addition, IGCP 732 is also linked to the Anthropocene Working Group (AWG) of the Subcommission on Quaternary Stratigraphy of the International Commission on Stratigraphy, and the ongoing research of potential GSSPs (Global Boundary Stratotype Section and Point, or ‘golden spike’), marking the onset of the Anthropocene as a chronostratigraphic unit of the Geological Timescale. Since the start of the project, more than 60 scientists from 27 countries have already become members of IGCP 732, thereof more than 50 % from developing countries. Contributions at international conferences help to increase the visibility of IGCP 732 and the urgent challenges the Anthropocene concept comes up with. This year, a workshop in Nairobi, Kenya (hybrid, including virtual participation) is planned, focusing on an African perspective on the Anthropocene. According to the goals of UNESCO IGCP, particularly young (female) scientists should be encouraged and financially supported to join the workshop. This project is supported by the International Programs of UNESCO IGCP and the Austrian Academy of Sciences.

Slope basin depositional model of the Paleogene Gosau Group of Gams on top of the incipient Eastern Alpine orogenic wedge (Austria)

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This study focused on the Paleogene deep-water depositional system of the Upper Gosau Group at Gams, Styria. The examined sections of Danian to Ypresian age (NP1–NP12) comprise sediments of the Nierental and Zwieselalm formations. The sections predominantly consist of thin- to medium-bedded, sandy and silty turbiditic beds, including fine breccia layers at the base, respectively silty shales or claystones on top. Further pelagic marls, slump beds and mass flow deposits occur. Normal grading, lamination, amalgamation of sandy beds and bioturbation are characteristics of all sections. The thickness of sandstone beds varies strongly from only centimeters to several meters, sandy/silty turbidite beds between 11 and 100 mm prevail. Complete Bouma intervals (Ta to Te) are scarce, but Tbcd intervals are often visible. Based on heavy mineral-, thin section-, microprobe- and paleoflow analyses, provenance was from the surrounding Northern Calcareous Alps (NCA) rocks and exhuming metamorphic Upper Austroalpine units to the south. Provenance indexes based on heavy mineral assemblages indicate the dominance of an upper greenschist to lower amphibolite metamorphic facies source of the investigated sediments. In addition, biogenic-calcareous material was delivered into the basin by adjacent contemporaneous shelf zones. The lithic arenites of the Paleocene Gosau Group show a peculiar composition for sandy turbidites, due to the source area, the metamorphic basement units of the Austroalpine and the extended reworking processes at the southern margin of the NCA and across the shelf of the Austroalpine microplate. The sedimentary depocenter was situated at the slope of the incipient Alpine orogenic wedge, in frontal parts of the NCA, facing the subducting Penninic Ocean/Alpine Tethys. The evolution of the basin was connected to the eoalpine and mesoalpine orogeny, and the adjunctive transpressional setting. Thus, a comparison of the depositional system of Gams with traditional submarine fan models of turbidite/deep-water deposition is complicated, due to the model premise of an unconfined, often large turbidite complex, which developed on the slope and expanded further at the toe of slope. The Gams slope basin provided a small depositional area and accommodation space on the incipient alpine orogenic wedge, and the pervasive tectonic deformation of the NCA destroyed and obscured important features of the formerly confined source-to-sink system. However, the Gams deep-water depositional system is interpreted as a submarine fan, deposited into a small confined slope basin, positioned along an active continental margin, bound and influenced by (strike-slip) faults, related to crustal shortening. The development of the Gams slope basin and its infilling sequences was mainly dominated by tectonism and sediment supply, rather than by eustatic sea-level fluctuations. General greenhouse conditions, with enhanced chemical weathering under seasonal conditions are assumed for the entire Gosau Group of Gams (Upper Cretaceous to Eocene), which enhanced erosion and facilitated a greater terrestrial sediment supply. Particularly, an increased input of siliciclastics around the PETM is noticeable, including significant numbers of sandy turbidites. The basin was cut off during the Eocene due to renewed orogenic activity. A Quaternary analogue for the Paleogene basin setting of the Gams area is represented by the Santa Monica Basin in the California Continental Borderland.

Paleoenvironmental evolution of the Vienna Basin during the Miocene

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The Vienna Basin (VB) is an about 200 km long and 55 km wide, rhomboid extensional basin, covering large parts of eastern Austria and extending northwards into the Czech Republic and eastwards to Slovakia. It originated during the Early and Middle Miocene and is composed of several horst and graben structures forming different subbasins. Each subbasin yields an own geodynamic evolution and deviating paleobathymetric developments during the Miocene marking the VB as one of the largest oil and gas fields in on shore Europe. During the last decades the OMV AG is leading in the investigation of the northern and central VB and numerous boreholes with up to 8,500 m depth (Zistersdorf ÜT 2a) were studied (mostly unpublished OMV internal reports). Still, the correlation of Neogene deposits throughout the basin remained ambiguous in regards of biostratigraphic correlation, paleoecological and paleobathymetrical reconstruction, due to the complex fault systems of the VB. To resolve persistent shortcomings in correlation of target horizons, a project was initiated covering 717 samples of 54 wells roughly aligned on a NNE to SSW transect. Micropaleontological data have been combined with core-log data, such as spontaneous potential, resistivity as well as modern 3D seismic data leading to the first continuous reconstruction of paleoenvironmental evolution of the VB from the Early Miocene to the Middle Miocene spanning 6.4 million years. Beside paleoenvironmental and biostratigraphic analyses, we applied transfer functions using benthic and planktonic foraminifers to analyze the water depth evolution and ecological trends like oxygen availability, salinity, trophic levels, bottom and sea surface temperature. Plankton-Benthos ratio was also applied to gather information of bathymetrical changes but showed troubling results. Hence, we propose not to use P/B ratio as main indictor for sea-level fluctuation reconstructions in highly active marginal areas like the VB. Using the transfer function of benthic foraminifers, dramatic changes in the depth profile with concomitant ecological changes through time, which coincide with shifts of prevailing tectonic regimes, could be observed. Bathyal conditions were established during the Early Miocene piggy-back stage and the early Middle Miocene extensional phase. A clear shallowing trend from upper bathyal to inner neritic conditions occurred during the Middle Miocene extensional tectonic phase. Bottom water temperatures indicate a cooling during the early and middle Badenian (Langhian), which seemingly contradicts the global warming of the Middle Miocene Climatic Optimum (MMCO) and a subsequent warming, which contrasts the expected trend following the cooling of the Middle Miocene Climatic Transition. Both trends are discussed as result of bathymetric evolution of the VB and intense upwelling during the early and middle Badenian. This project is financed by OMV-AG.

A robust technique to predict formation fracture pressure of North Sea-Volve oil field using petrophysical log data

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Prediction of formation fracture pressure (FP) is necessary to optimize well geometry, analyze well stability, and design mud programs. Precise determination of FP helps prevent mud loss during drilling, production and injection selection, and hydrocarbon migration flow mapping. This study combines empirical equations with machine learning (ML) technique namely extreme gradient boosting (XGBoost), recurrent neural network (RNN), and convolutional neural network (CNN) to identify a robust approach for FP prediction using petrophysical log data. For the selection of a robust ML model to predict FP, some rudimentary steps are followed. The process starts with the collection of relevant well log data from three wells of Volve oil field, Norway, and sorting and normalizing all the gathered variables. Afterwards, the best input variable for FP prediction has been identified using the feature selection algorithm. The selected ML model is trained and tested using the gathered petrophysical logging data. Statistical analysis is carried out to analyse the performance of the applied ML model by calculating the mean absolute error (MAE), root mean square error (RMSE), relative absolute error (RAE), root-relative square error (RRSE), and coefficient of determination (R2). The best ML model with low prediction error is tested on another petrophysical well data of the same field to validate and assess the reliability and ability of the selected ML model. In addition, a parametric analysis is carried out to identify the effect of different petrophysical parameters on formation fracture pressure. According to the authors' knowledge, this is the first time a comparative study is done on XGBoost, RNN, and CNN ability to prediction formation fracture pressure.

Jurassic and Cretaceous phosphatic events and their palaeoceanographic significance during geotectonic evolution of the Pieniny Klippen Basin (Carpathians)

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The Pieniny Klippen Belt (PKB) represents a boundary zone between the Outer and Central Western Carpathians and is interpreted as a separate branch of the north-westernmost Tethyan Ocean (Pieniny Klippen Basin – PKBs). Several facies zones can be distinguished, from shallowest zone (so-called Czorsztyn Succession – corresponds to submarine ridge) trough transitional zone (Niedzica and Czertezik successions) up to deepest one (Branisko and Pieniny successions) in the axial part of this basin. The Czorsztyn, Niedzica and Czertezik successions accumulated in subtidal/neritic shelf environments of the submarine Czorsztyn Ridge and its southeastern slope, while palaeogeographical orientation of the Czorsztyn Ridge was from NE to SW. In whole PKBs history at least three phosphatic events took place in: (i) Early Bajocian, (ii) Berriasian and (iii) Albian times. In the late Early Bajocian (i), just after Czorsztyn Ridge originated by tectonic uplift, sedimentary features recorded condensation episode during start of crinoidal limestones sedimentation (even up to 150 m in thickness). The base of the crinoidal limestones is very sharp and directly overlying, with a stratigraphical hiatus (ca. 2 Ma), the oxygen-depleted dark/black Fleckenkalk/Fleckenmergel-type deposits of Toarcian lowermost Bajocian in age. This part of crinoidal limestones consists of phosphatic concretions pavements, large phosphatic macrooncoids (up to 8–10 cm), light-greenish clasts of micritic limestones, pyrite concretions, and fossils as ammonites, brachiopods and bivalves. Phosphatic concretions (up to 6 cm) occur in almost all PKB successions exclusively within lowermost part (first 1.0 m above base) of crinoidal beds, which is isochronous event. On the other hand, very rapid change of sedimentation from oxygen-depleted environments (during Toarcian–earliest Bajocian) to carbonate sedimentation is record of rapid vertical tectonic movements of the Czorsztyn Ridge and adjacent areas and may be also reflect palaeoceanographical changes after this tectonic uplift and origin of upwelling currents, for which such condensation and phosphatic structures are typical. The second (ii), Berriasian episode of phosphatisation within PKBs was connected with post-Tithonian (Neo-Cimmerian) tectonic uplifting of the Czorsztyn Ridge and surroundings, including Niedzica Succession. The presence of phosphate-rich deposits (phosphorites and microbial phosphate macrooncoids) in this succession, which should be localized in a palinspastic reconstruction near shelf-edge slope boundary, support the idea of upwelling currents as well. In the PKBs this idea is additionally supported by Berriasian brachiopods/crinoids-rich beds of the Czorsztyn Succession and their distribution probably have also been controlled by the upwelling currents, where nutrient-rich oceanic water formed such conditions which caused the proliferation of benthos. The third (iii), Albian episode of phosphatisation of marly deposits on sea-floor occupied by the Czorsztyn Succession zone are represented by phosphatic stromatolites, lithoclasts and microbialite-coated bioclasts within beds of different thickness (a few cm up to dozen ones). Usually, they occur at the base of Albian marls/marly limestones which cover erosional surfaces of older limestones with several fossil-karst phenomena originated as effect of at least two episodes of tectonic uplift and emersions of the Czorsztyn Ridge/Czorsztyn Succession zone.

The sedimentological death mask of a dying glacier

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The Pasterze is Austria's largest glacier, and it is experiencing rapid downwasting and retreat. A mosaic of complex sedimentary deposits has been produced in recent years, which have not hitherto been studied, yet provide excellent lessons into the facies distribution expected from a dying valley glacier. In this paper, we present a new glaciological-geomorphological-geological map for the glacier in July 2021. Freshly exposed (since 2018) tills and flutes constitute a subglacial sediment-landform assemblage. An ice-marginal sediment-landform assemblage comprises meltwater streams, a delta system, and proglacial lake terrace deposits. The supraglacial assemblage, meanwhile, includes fossil englacial channel deposits revealed by ablation, together with debris bands, rockfall deposits, and supraglacial channel deposits. Collectively, these sediment landform assemblages constitute the building blocks of a dying glacier landsystem.

Fachfremder Unterricht in der Induktionsphase: Eine Herausforderung für den Eintritt in den Lehrberuf?

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Dass Lehrkräfte nicht ausschließlich jene Fächer unterrichten, für die sie lehrberechtigt sind, ist aus anderen Ländern seit langem bekannt. Aber auch an österreichischen Mittelschulen ist fachfremder Unterricht keine Seltenheit mehr. Internationale Forschung weist darauf hin, dass fachfremder Unterricht besonders für neueinsteigende Lehrkräfte eine zusätzliche Herausforderung darstellen kann. Da es hierzulande bislang noch keine systematische Untersuchung zum Einsatz von Lehrkräften in Fremdfächern gibt, wurde eine qualitative Interviewstudie durchgeführt, um sich der Thematik explorativ zu widmen. Dabei zeigte sich, dass viele der bereits in bisherigen Studien identifizierten Herausforderungen auch auf österreichische Lehrkräfte zutreffen. Die gemachten Erfahrungen hingen dabei sowohl vom jeweiligen Unterrichtsgegenstand als auch von der betroffenen Lehrkraft ab. Eine wichtige Rolle spielte außerdem der Schulkontext. Während der fachfremde Einsatz für manche Lehrkräfte von großen Schwierigkeiten geprägt war, die mitunter dafür sorgten, dass kaum Freude beim Unterrichten aufkam, bereitete er anderen Lehrkräften so große Freude, dass sie sich vorstellen konnten, weiterhin fachfremd zu unterrichten. Auch wenn die Lehrkräfte im Zuge ihres ersten Dienstjahres unterschiedliche Unterstützung erhielten, wurde deutlich, dass nicht alle Formen der Unterstützung fachfremden Lehrkräften Entlastung bieten. Als besonders entlastend stellten sich ein offenes und hilfsbereites Fachkollegium, sowie die Möglichkeit im Team-Teaching zu unterrichten heraus. Fachfremdes Mentoring half den neueinsteigenden Lehrkräften hingegen kaum. Insgesamt zeigt sich die Notwendigkeit, fachfremden Unterricht in Österreich sowohl in Hinblick auf betroffene Lehrkräfte als auch Schülerinnen und Schüler noch stärker systematisch zu untersuchen.

Preliminary results of the InStRikE project: risk-assessment of induced seismicity in geothermal fields

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In recent years, the transition to more sustainable energy put a lot of attention on geothermal energy, seen as a carbon-free alternative. However, geothermal energy is not completely free of environmental risk and, in some circumstances, proved to be associated with an unacceptable level of induced seismicity, which resulted in the termination of several projects worldwide. This led to a progressive concern on geothermal activities, resulting into intense research on the potential relation of induced seismicity with those activities. Induced seismicity occurs mostly after massive fluid injection during the stimulation phases (when necessary), but it might happen also during regular operations, mainly due to pore pressure and thermal perturbation of the reservoir. However, an assessment of the induced seismicity risk on geothermal plants during the planning phase is still challenging. The Induced Seismicity Risk Estimation (InStRikE) project supported by FFG (Österreichische Forschungsförderungs GmbH) aims to develop a smart planning tool for the assessment of the risk of induced seismicity during geothermal activities. The first part of the project is a systematic collection of various parameters from already existing geothermal projects, retrieved from various publicly available sources (papers, abstracts, published reports, various databases, etc.). The aim is to create a database as much comprehensive as possible. Subsequently, the database will be further integrated with data provided by the geothermal operators, willing to share their experience and information. The various entries in the database will be analyzed by advanced statistical methods, such as multivariate analysis, neural networks, combinatorial optimization. We intend to gain new knowledge to better understand the relationship between geothermal operations, geologic and geomechanical settings, and the risk of induced seismicity. Different risk parameters are analyzed including: geologic characteristics (regional setting, play type, lithology, presence of faults, natural seismicity, geodynamic setting, porosity, permeability, etc.); geomechanical parameters (SHmax orientation, rock properties, initial pore pressure, stress gradients, stress regime, etc.); operational conditions (injection/production pressures, injection/production rates, T of produced vs. reinjected fluids, depth of operation etc.). If available, magnitude and date of the maximum seismic event observed during (or after) the operational period are also collected in the database. The project is currently in an early stage; we are in the midst of populating the database starting with about 150 different geothermal fields worldwide. However, the preliminary analysis already allows a good correlation between some of the collected parameters and induced seismicity. We see that about 30 % of the geothermal fields operate without any seismicity, about 23 % show little seismicity during their operations ($M < 2$), 24 % are associated with moderate seismicity ($2 < M < 4$), whereas the remaining ~13 % experienced intense seismicity ($M > 4$). In the current status, there is no reliable seismicity information on the remaining 10 % of the geothermal fields during operations.

Geodynamic remarks in the deep borehole TH1 (Vienna Basin)

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The Vienna Basin (VB) is a pull-apart basin formed in the Miocene due to the sinistral movement along the Mur-Mürz-Vienna Basin Transfer Fault. The sigmoidally shaped basin formed at large-scale left-step of the fault system. The VB infill consists of up to 6,000 m of Early Miocene-Quaternary sediments, whereas the substrate is represented by the imbricated Eastern Alps including the Northern Calcareous Alps (NCA). Seismicity occurs mainly along the SE margin, at 3–10 km of depth, and is of moderate magnitude. Recent activity of the VB is further indicated by captured rivers and faulted Pleistocene terraces. TH1 was drilled NE of Vienna to investigate the potential for deep geothermal operations in the VB. The well is situated close to the Aderklaa Fault system (ADF), which offsets the Gänserndorf Terrace (Pleistocene). In this area the ADF displays a curved shape, striking NNE in the northern part and NNW to the South (close to TH1). The main target of the well TH1 was the fractured carbonates of the VB substrate, below 3,400 m, however, instead of the expected Hauptdolomit, other formations of the NCA were encountered (Furth Formation, Werfen Formation, Lower Gosau Group). The well was drilled to a depth close to 4,220 m, where repeated borehole collapses led to stop of the operations. Several data were acquired in TH1: open hole logs (OHL), 3 LOT and micro-resistivity image log (FMI) (3,473–3,888 m). Analysis of the FMI revealed a complex structure in the NCA section, with a normal fault between Werfen Formation (in the hangingwall) and Lower Gosau Group (in the footwall). The fault strikes NNW and dips 54° to the WNW, parallel to the local orientation of the ADF, as also indicated by newly acquired 3D seismic data. The analysis of the drilling induced failures indicates only borehole breakout (BO). In both, Furth and Werfen Formation, BO is oriented close to E-W, whereas in the Lower Gosau Group the BO is oriented SW-NE. Thus, there is a rotation of about 45° at the NNW-SSE normal fault of the ADF. Similar rotations of the BO close to faults are often interpreted as resulting from active faulting. Rock properties (UCS, coefficient of internal friction, elastic moduli) were derived from OHL, based on wellknown correlations of log data with the petrophysics. Vertical stress and mud pressure were modeled respectively from density log and mud weight of the drilling report. The pore pressure is close to hydrostatic in the VB infill (used mud density 1.12 g/cm³) and moderately overpressured in the NCA (used mud density 1.22–1.24 g/cm³). The magnitudes of the two horizontal stresses were modeled with poroelasticity method and calibrated against the LOT (for Shmin) and by comparing the predicted drilling induced failures and actual failures observed on the FMI data (for SHmax). The model indicates a NF stress field over the entire interval, that is close to critically stressed conditions in the NCA. These remarks indicate that not only the central sector of the ADF is active, where it offsets the Gänserndorf Terrace, but also the southern part, as observed in well TH1. Deep geothermal activities are associated with a pore pressure perturbation in the area of operations, which under some circumstances could lead to both induced and triggered seismicity. In the TH1, fluid migration under operational conditions (injection flow and pressure) should be carefully evaluated, in order to minimize the risk of reactivating faults of the ADF.

Different ages of granitic blocks in the Waschberg-Ždánice Unit and Allochthonous Molasse as indication for Moldanubian and Moravian rocks in the Bohemian spur

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The Bohemian Massif continues below the Eastern Alps as a southeast-directed basement promontory often referred as Bohemian spur (Tari, 2008). According to wells in the Alpine-Carpathian Foredeep, it consists of Variscan basement rocks (Matura, 2006) of the Moldanubian and Moravian Superunit. However, the composition of the Bohemian spur below the Alps can be inferred from blocky layers embedded in the Waschberg-Ždánice Unit and Allochthonous Molasse, representing the northernmost and youngest tectonic units of the Alps. In Lower Austria, the Waschberg-Ždánice Unit is composed of late Oligocene to early Miocene shales, marls and sandstones with polymict blocky layers containing “exotic” blocks from the crystalline basement. These layers are indicating widespread olistostromes surrounding giant olistoliths in the Eggenburgian stage (Gebhardt, 2021). The Allochthonous Molasse south of the Danube consists of sediments deposited in the Alpine-Carpathian Foredeep, accreted to the front of the orogen from middle Miocene onward. Its eastern part is composed of Eggenburgian to early Ottnangian marls with intercalation of sandstones and occasionally blocky layers also with “exotic” blocks. Granitic blocks from several outcrops of both units have been investigated by geochemical and geochronological methods to get insight to their source area on the Bohemian spur. From Waschberg to Niederhollabrunn blocky layers show a polymict composition marked by “exotic” granites with amphibole and pinkish K-feldspar. Furthermore, various granite gneisses, porphyric granite and minor amphibolite and marble occur. Additional migmatic paragneiss feature the blocky layers in the Allochthonous Molasse at Königstetten. The granitic rocks from blocky layers show an overall peraluminous composition. Additionally, higher SiO_2-contents connected with increased Rb/Sr-ratios indicate considerable magmatic fractionation of largely S-type granites. Nevertheless, granites with pinkish K-feldspar exhibit low $^{87}Sr/^{86}Sr$-initial ratios (0.705–0.707, 300 Ma) pointing to a significant I-type component in their magmatic source. U/Pb dating of zircons points to three different age groups: Three granites with pinkish K-feldspar exhibit ages around the Carboniferous-Permian boundary (302–290 Ma). A metagranite from Königstetten records a Carboniferous age of 323 Ma and two granite gneisses point with 587 Ma and 615 Ma to a Neoproterozoic age group. By comparing the Bohemian spur which is indicated by the granitic blocks with the adjacent Variscan basement there are similarities and differences. The Moldanubian Superunit contains a wide range of I- and S-type granites (Vellmer & Wedepohl, 1994) which are characterized by magmatic ages of 340–310 Ma (Finger et al., 2009). Nevertheless, granites equivalent in age and composition to the conspicuous granites with pinkish K-feldspar are unknown. Otherwise, granites similar to the metagranite from Königstetten are widespread in the South Bohemian Batholith. The Neoproterozoic granite gneisses indicate rocks from the Moravian Superunit as further source for the blocky layers. For instance, the Bíteš gneiss which is closest has a magmatic age (Friedl et al., 2004) similar to a granite gneiss sample from the Waschberg. It is important to note that the Rb/Sr cooling ages of biotite from all granitic blocks range from 300 to 230 Ma (Wegner et al., 2013), arguing for a prolonged cooling history of the hidden Bohemian spur.

Vanadium leaching from thermochromic cement

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In times of global warming, the improvement of a building's energy-saving performance could be a smart way to reduce the increasing demand for resources. One possible approach is the use of thermochromic materials, which can reversibly change their optical response at a specific transition temperature. This property makes these materials very attractive for applications related to the thermal adaptation of buildings, allowing a potential use as smart regulators. Up to now, developments in this area have mainly focused on smart windows, but most recently a new approach related to the use of these materials in cement-based matrices for adaptive building envelopes has been proposed. The thermochromic properties of the materials increase solar heat absorption at cold conditions, while enhancing the rejection of solar heat to cool it during hot periods, therefore improving the building's overall energy efficiency. The use of thermochromic materials based on organic leuco dyes has proven problematic due to the degradation of the thermochromic functionality upon exposure to solar radiation. This problem can be overcome by using monoclinic vanadium dioxide (VO_2), which exhibits a reversible insulator-metal phase transition and the corresponding reflectance change in the near-infrared wavelength range. Recent results have confirmed the thermochromic behaviour of VO_2-based mortars. However, other aspects related to the long-term stability and performance of the VO_2-cement systems have not yet been addressed. In this study the leaching behaviour of VO_2-cement pastes was analysed by immersing the hardened materials in water and by measuring the elemental concentrations in the leachates as a function of time by means of inductively coupled plasma optical emission spectroscopy (ICP-OES). The study was complemented with a hydration assessment conducted by isothermal calorimetry, X-ray diffraction and electron microprobe analysis. The results of the experiments demonstrate that the substitution of cement by VO_2 leads to a retardation of the hydration process. The increased solubility of vanadium in alkaline environments consequently causes the cement matrices to lose 30 % of the vanadium and even up to 85 % in powdered samples after 74 days immersed in water. Curing the samples in a carbonation chamber does not seem to provide enough protection against the problematic leaching behaviour. Further experiments need to be performed to stabilize the VO_2 particles within the matrix and obtain a more durable and efficient material.

Polzberg – Trias Konservat-Lagerstätte von Weltruf

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Paläobiota aus fossilreichen Konservat-Lagerstätten sind kostbare, oft einzigartige Quellen für taxonomische und paläobiologische Informationen. Diese liefern einmalige Erkenntnisse über Vergesellschaftungen, Nahrungsketten, Ernährungsgewohnheiten sowie Räuber-Beute Verhältnisse in marinen Ökosystemen. Eine umfangreiche und diverse Sammlung (n > 10.000) von verschiedenen marinen Taxa aus dem frühen Karnium der Polzberg Konservat-Lagerstätte bei Lunz am See (Nördliche Kalkalpen, Niederösterreich) wurde nun bearbeitet. Die fossilreichen Schichten wurden während des Julian 2 Ib (*Austrotrachyceras austriacum* Zone, *Austrotrachyceras minor* Biohorizont) abgelagert. Die fein laminierten Reingrabener „Schiefertone“ beinhalten massenhaft und gut erhaltene Vertreter der marinen Nahrungsketten des Karniums. Invertebraten mit der Bivalve *Halobia*, den Ammoniten *Austrotrachyceras* und *Paratrachyceras* und dem tintenfischartigen *Phragmoteuthis* dominieren über die Vertebraten mit Fischen aus der Gruppe der Strahlenflosser. Die Erhaltung von Weichteilen ist sowohl von Ammoniten in Form von Kieferapparaten und Muskelabdrücken, als auch von fragilen Gruppen wie Vielborstern und Krebstieren bekannt. Über 10.000 Fossilien konnten aus der Basis der Reingrabener Schichten gesammelt werden. Dabei handelt es sich um Material aus den historischen Stollen, das in den vergangenen Jahren durch tausende neue und Schicht-für-Schicht geborgene Funde ergänzt werden konnte. Die diverse Vergesellschaftung umfasst Ammoniten (*Austrotrachyceras*, *Paratrachyceras*, *Carnites*, *Sageceras*, *Simonyceras*), Unterkieferelemente (*Anaptychus lunzensis*) und Oberkiefer der Trachyceraten, Tintenfische (*Phragmoteuthis*, *Lunzoteuthis*), Muscheln (*Halobia*, *Bivalvia* indet), Schnecken (Caenogastropoda/Heterobranchia), thylacocephale Gliederfüsser (*Austriocaris*, *Atropicaris*), Krebstiere (Zehnfußkrebs *Platychela* und *Antrimpos*, Asseln mit *Obtusotelson* und *Discosalaputium*), Muschelschaler (*Eustheria*), vielborstige Würmer (*Palaeoaphrodite* sp., *Eunicida* indet.), Strahlenflosser (*Saurichthys*, *Polzbergia*, *Thoracopterus*, *Gigantopterus*, *Peltopleurus*, *Habroichthys* etc.), Knorpelfische (*Acrodus*), Quastenflosser (“*Coelacanthus*”), ein Lungenfisch (*Tellerodus*) und einige Conodonten-Cluster (*Mosherella*). Würgereste (*Regurgitalites*) produziert von großen durophagen Fischen und Koprolithen von fischfressenden Strahlenflossern begleiten die Polzberg Paläobiota neben seltenen Pflanzenresten von Koniferen (*Voltzia*). Zahlenmäßig überwiegen aber die benthonischen halobiiden Bivalven. Die aktiv schwimmende Makro-Fauna ist dabei von nektonischen Vertretern der Fische, Ammoniten und Tintenfische dominiert. Die gesamte Fauna der Polzberg Konservat-Lagerstätte und die exzellente Erhaltung verschiedener Taxa und Exemplare stellen ein Fenster in die Ober-Triassische Vergesellschaftung und Paläo-Umweltbedingungen während der so genannten Karnischen „Regenphase“ (Carnian Pluvial Episode, CPE) im frühen Mesozoikum dar. Das Auftreten des Süßwasser-Lungenfisches Tellerodus und der Kiemenfußkrebse (Branchiopoden) *Eustheria*; einem Bewohner brackischer und süßwasserdominierter Lebensräume, zeigt den zumindest zeitweisen Einfluss von Süßwasser-Einträgen oder von Sediment-Transport Events in das marine Reifling Intraplattform-Becken (Polzberg Sub-Becken). Die Polzberg Paläobiota wurden während der globalen CPE abgelagert. Die weltweiten Auswirkungen der erhöhten vulkanischen Aktivität sind auch für die sich wandelnden Umweltbedingungen des Polzberg Sub-Beckens verantwortlich und resultierten in der Bildung von terrigen-beeinflussten und zunehmend tonigeren Reingrabener „Schiefern“ mit der darin befindlichen Polzberg Konservat-Lagerstätte, einer karnischen Fossil-Lagerstätte von Weltruf.

Taphonomy of the total belemnoid fauna from the Polzberg Konservat-Lagerstätte (Upper Triassic, Northern Calcareous Alps, Austria)

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Coleoid cephalopods are widespread from the Palaeozoic throughout the whole geological time scale. Biomechanical advantages such as the canalicular, light-weight design of their supporting cartilaginous structures, as well as their dietary flexibility are reasons for their evolutionary-biological success in fossil and recent marine environments. In comparison to other fossils sites, the calcareous to clayey deposits of the Polzberg Konservat-Lagerstätte near Lunz am See (Lower Austria) comprise abundant Phragmoteuthids. Nevertheless, this Mesozoic order only makes up about 5 % of the cephalopod fauna and 3.9 % of the total Polzberg palaeobiota. In this study their often exceptionally preserved remains, such as phragmocones, proostraca, jaws, arm hooks and the cephalic cartilages of *Phragmoteuthis bisinuata* were collected bed-by-bed, measured and evaluated concerning its taphonomical and taxonomical content. Coleoids represent strong and fast predators but also play a key role as favoured prey as suggested by irregular fragmentation of *phragmoteuthid proostraca*. A few specimens were even found directly associated with small thylacocephalans of the species *Atropicaris striata*, supporting their role as scavengers in this low-oxygen ecosystem. In the present study 205 belemnoid phragmocones/proostraca and 19 uniquely preserved, mineralised, cephalic cartilages from recent excavations were collected bed-by-bed. Additional observations and measurements were done on more than 100 phragmocones and proostraca from collection material. Overall numbers of preserved individuals increase throughout the section with time, while the average sizes of the phragmocones and proostraca decrease. The oldest part of the section comprises calcareous deposits with whitish preserved, often larger proostraca, while the smaller specimens from the young and clayey layers mainly appear as pyritized fragments. The number of individuals varies greatly in the lower part of the outcrop, while they are more balanced in the younger layers. Rapid mineralisation processes are essential for the preservation of soft tissues and are strongly influenced by the present environmental factors. Even within one carcass, these factors can fluctuate in so-called “micro-habitats”. Details of preserved soft tissues such as ink sacs and cephalic cartilages were examined by Scanning Electron Microscopy (SEM). Supplementation of the taphonomic pattern of the Polzberg Konservat-Lagerstätte is achieved by geochemical analyses.

Physical and geomechanical characterization of volcanic rocks from Styria

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This study analyses the dependence of various rock mechanic parameters on geological characteristics for volcanic rock from Styria. It is common for ground models to only focus on geologic parameters or geotechnical parameters, but not both. Therefore, it is important to determine which geological characteristics have the greatest influence on the geomechanical parameter. In this study four parameters – density, porosity, wave velocity, and uniaxial compressive strength – were tested to demonstrate this for a set of volcanic rocks from Styria. Four grey trachyandesite and three red trachyandesite samples from the Klausen quarry and one basalt sample from the Klöch quarry provided the data used in this analysis. The red trachyandesites appear from visual observation to be altered versions of the grey trachyandesites, whereas the basalt appears unaltered. The samples were cored and a series of physical and mechanical experiments were conducted on the cores. The data collection procedure for each core sample started with the measurement of the dry density, saturated density, and porosity. Then, an ultrasonic device was used to determine the p- and s-wave velocities to calculate the dynamic elasticity moduli. Lastly, the cores were deformed in a compression testing machine to the maximum stress upon which macroscopic failure occurred, and the resultant stress and strain profiles were recorded. Data from these experiments indicate a linear relationship between porosity and density, a linear relationship between compressional and shear wave velocities, that basalt and grey trachyandesite exhibit brittle behaviour whereas red trachyandesite exhibits brittle-ductile behaviour, and that porosity influences the peak strength as well as static and dynamic modulus of elasticity. The peak strength, p-wave velocity and density also correlate to the lithological characteristics, showing a progressive increase in all three parameters from the altered red trachyandesite (acidic to intermediate) to the unaltered grey trachyandesite (acidic to intermediate) towards the basalt (mafic). These findings show that the geological characteristics of volcanic rocks from Styria have a direct influence on the physical and geomechanical characteristics, as also observed for volcanic rocks from other locations.

Wissen um zu schützen – die Bedeutung einer detaillierten geologischen Karte für Gefahrenzonenplanung und Risikomanagement im alpinen Raum

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Gefahrenzonenplanung und Risikomanagement sind Begriffe, welche immer häufiger gebraucht werden und schon fest im alltäglichen Sprachgebrauch eingebaut sind. Insbesondere dann, wenn zudem das überstrapazierte Wort „nachhaltig“ im selben Satz auftaucht. Interessanterweise kommen dann aber sehr schwammige Modelle zur Anwendung, wenn es zur Umsetzung der Gefahrenzonenplanung und zum Einsatz eines Risikomanagements kommen soll. Dann werden vielfach statistische Modelle herangezogen, Simulationen mit digitalen Höhenmodellen bemüht und vor allem – um ganz modern herauszukommen – Satellitendaten ausgewertet und angepriesen, deren Auflösung zumeist unzureichend sind; deren Vor- und Nachteile und vor allem deren Anwendungsbereiche und Grenzen nur den wenigen wirklichen Experten bekannt sind. Zudem werden geologische und geothematische Karten aus dem letzten Jahrhundert als Grundlage verwendet, welche keinesfalls dem Stand der Technik und der Wissenschaft entsprechen. Das heißt nun überhaupt nicht, dass die Karten falsch sind – sondern lediglich, dass die Karteninhalte nicht oder nur sehr begrenzt jene Informationen enthalten, die für eine moderne Gefahrenzonenplanung notwendig wären. Diese Fragestellung war zur Zeit ihrer Erstellung nie im Fokus der Ersteller. Was es wirklich als Datengrundlage für eine wissens- und faktenbasierte Analyse und Darstellung der hydrogeologischen Gefahren braucht, sind detaillierte geologische und thematische Karten in einem Maßstab, der für die Raumplanung notwendig ist: 1:25.000, wenn geht 1.10.000. Nur so lassen sich die notwendigen Inhalte und Informationen darstellen, die letztlich als Eingangsparameter für die Simulationen, Szenarienbildungen und Berechnungen dienen. Nur so können Kartenderivate entstehen, die für die Raumordnung und den Zivilschutz nutzbar sind.

Spodumene pegmatite resource potential of Austria

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Pegmatites are widespread in the Austroalpine basement units of the Eastern Alps. Some formed during the Varican or Alpine collisional events, but most developed during Permian lithospheric extension. Spodumene is present in anatectic Permian pegmatites only. To date, some 80 spodumene bearing pegmatite occurrences are known in Austria. Just a few other Li bearing minerals like liddicoatite, ferrisicklerite, triphylite, and holmquistite are found in trace amounts in these pegmatites. Minerals like petalite, eucryptite, amblygonite, lepidolite being substantial components of economically important deposits elsewhere in the world are absent. Whole rock geochemistry of spodumene pegmatites gives a range between 0.1 and ca. 2.5 wt.-% of Li_2O. Most of the spodumene pegmatites are zoned. Usually the outer zones contain no spodumene. Inner zones show variable grades of 30 vol.-% of spodumene at maximum. Many dykes of the biggest deposit in Austria, situated at Weinebene, are strongly sheared and can be termed mylonites comprising no megascopically visible zonation at all. At the Weinebene deposit, 15 individual spodumene pegmatite dikes have been discovered and 12.88 mt of ore resources grading 1 wt.-% Li_2O were documented until now. There is great unexplored potential at depth and in the dikes´ strike direction. For the delineation of provinces with highly evolved pegmatites more than 1,200 muscovites of different pegmatites were analysed by LA-ICP-MS. Ratios of K/Rb, K/Tl, K/Cs in micas are good indicators for the degree of fractionation of a pegmatite dike. Spodumene pegmatite muscovites show K/Rb-ratios of less than 100. In the neighbouring areas of spodumene pegmatites, muscovites of several barren pegmatites usually contain elevated concentrations of Rb resulting in low K/Rb ratios. The pegmatite muscovite K/Rb distribution gives confidence for new discoveries of spodumene pegmatites in underexplored areas like the central part of the Defereggen valley or the southern part of the Koralpe and others. Spodumene pegmatites are known from areas near Anger, St. Radegund, southern slope of the Gleinalpe, central part of Koralpe, Wölz Tauern, Falkenberg, Hüttenberg, Millstatt Seerücken, Kreuzeck Mountains, and Defereggen valley. Permian spodumene pegmatites are also reported from Southern Tyrol in comparable geological units. Most of these deposits have drawbacks for mining because of alternative land uses, environmental protection, civilization nearby and others. Besides the Weinebene deposit, the most promising potential for mineable spodumene is considered at the Millstatt Seerücken and the Defereggen valley. Valuable by-products could be quartz, feldspar and muscovite. In all investigated spodumene pegmatites beryl, Nb-Ta minerals, as well as cassiterite are too scarce to contribute to an economically feasible mining operation.

Perlitic textures in silica-rich rocks: Re-evaluation of volcanological and glass technical models

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Perlites are volcanic glasses of exclusively rhyolitic composition that contain curved fractures around still intact cores of glass. To achieve a more detailed view into the mechanisms controlling formation of fracture networks in volcanic glass and the understanding of microstructures and textures related to perlitic fractures, this study relies on a combination of volcanological and glass technical models supported by stochastic image analysis. The research is based on methodical investigations of 35 rock samples from 24 different locations from five continents (Americas, Eurasia, and Africa) and of different geological ages to cover a broad spectrum of textural variations. The process of perlitization creates a three-dimensional fracture network, which can only be found in rocks comprising elevated H_2O contents. Related studies on rhyolitic textures are sparse and it is widely debated if perlitic fractures form in response to hydration solely or due to thermal stress before hydration. The three-dimensional geometry of the fracture network, which links perlitization to a three-dimensional (paleo)strain field, was proven by computer-tomography measurements. Further investigations on the fracture network show that perlitic cracks form secondary and are always accompanied by primary sublinear quench fractures. The prevalent relation between the two discrete fracture sets is also determined by stochastic image analysis. It was additionally found that crack propagation is further advanced in old samples and ignimbrites because of longer elapsed time spans for crack propagation and the compaction of the glass itself. Crack propagation is supported by the presence of H_2O and increases with time whereby certain samples show several generations of perlitic fractures. Besides transmitted-light microscopy, the study includes electron microprobe- and thermal analysis techniques (DSC/TG analysis) to gain insights into fluid- and elemental compositions and mobilities. Pre-Cenozoic fully hydrated samples show no variations in fluid content between rim and core but an effect of differential depletion or enrichment can be observed, whereas younger samples with unbalanced water contents indicate incomplete hydration, which reveals a direct connection between alkali mobility and hydration of a rock. Perlitization is widespread in rhyolitic reservoirs and the fractures frequently amount to an important fraction of the total porosity. Porosity and permeability measurements were conducted to provide an insight into pore space characteristics. It is shown that they can be either improved or deteriorated through post-volcanic, low-temperature alteration processes, especially abundant in pre-Cenozoic samples. Volcanic glasses are not only important as prolific reservoirs in the oil and gas industry, as they often provide storage capacity in geothermal reservoirs and boast various other applications. It is found that perlitic fractures can form by thermal shock at temperatures just below glass transition temperature, but crack propagation and initiation of subsequent generations of rounded cracks is most likely linked to strain which is induced by continued hydration of a volcanic glass.

Steinreiche Steiermark – Erdgeschichte begreifbar machen. Unterlagen für die Freilanddidaktik der Sekundarstufe I und II

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Das System Erde zu verstehen und aktuelle Veränderungen objektiv interpretieren und diskutieren zu können, setzt ein vernetztes Denken auf Seiten der Schülerinnen und Schüler voraus. Ein solches zu erlangen, erfordert einen umfassenden interdisziplinären Wissens- und Erfahrungsbestand, der jedoch von den Lernenden erst im Zuge ihrer schulischen Ausbildung erworben werden muss. Eine Möglichkeit dies im Unterricht zu ermöglichen, bietet ein Rückblick in die Erdgeschichte des Systems Erde, da sich im Verlauf seiner langen und ereignisreichen Geschichte unzählige Referenzen für das Verständnis aktueller Entwicklungen finden. Den Erdwissenschaften wird in der schulischen Ausbildung eher eine untergeordnete Rolle zugeschrieben. Zwar ist die Implementierung der Erdwissenschaften im schulischen Curriculum geregelt, aufgrund der Fülle an zu thematisierenden Inhalten im Biologieunterricht ist die Ausschöpfung ihres didaktischen Potentials jedoch deutlich beschränkt. Dabei könnten insbesondere die Erdwissenschaften einen wichtigen Beitrag zum Verständnis globaler systemischer Prozesse, wie Klimawandel, Rohstoffknappheit oder Artensterben leisten, die in der heutigen medialen Berichterstattung omnipräsent erscheinen. Aus didaktischer Sicht kann hierbei ebenso ein Paradigmenwandel von einem theoriebasierten multimethodischen Unterricht hin zu aktiven handlungsorientierten Lernsettings im Sinne von freilanddidaktischer Arbeit vollzogen werden. Dadurch könnte ein Fokus auf das Naturerlebnis an sich, in Form von Exkursionen oder auch Freilandarbeit an außerschulischen Lernorten, gelegt werden. Neben der allseits geforderten Bewusstseinsbildung könnten hiermit auch Naturerlebnisse das Verständnis komplexer biologischer Prozesse erleichtern. Die Anforderungen, die eine solche Freilandarbeit an die Schülerinnen und Schüler, insbesondere aber auch ihre Lehrpersonen stellt, ist unumstritten, weshalb es einer konkreten und verlässlichen Vorbereitung bedarf, um den Lernenden eine mögliche Basis für ein intendiertes vernetztes Denken zu schaffen. In diesem Sinne wurde ein Exkursionsführer sowie ein Gesteinskoffer konzipiert, der es Lehrpersonen ermöglichen soll, mit ihren Schülerinnen und Schülern die Erdgeschichte der Steiermark an ausgewählten Geopunkten zu erleben. Diese reflektieren 420 Millionen Jahre Wandel des Systems Erde. Von tropischen Korallenrasen des Devons, Klimaänderungen der Kreide bis zum neogenen Vulkanismus und „letztem“ Meer der Steiermark bietet sich die Möglichkeit anhand der „steirischen“ Erdgeschichte komplexe Prozesse zu diskutieren, Analogien zu aktuellen Diskussionen zu finden und schlussendlich die Natur selbst zu erleben. Bei der Erstellung des Exkursionsführers wurde besonderer Wert darauf gelegt, die einzelnen Exkursionspunkte möglichst genau aufzubereiten. Neben detaillierten Anfahrtsbeschreibungen finden sich ausführliche petrographische Beschreibungen der auffindbaren Gesteine, sowie eine Darstellung der damaligen Geobiologie.

Alpine metallogensis – reloaded

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The metallogenetic development of the Eastern Alps has been controversially discussed for over 100 years. A new model over the course of a modified Wilson cycle over the past 300 million years (Ma) is based on radiometric dating of ores, the resolution of the tectonic structure of the Eastern Alps, the paleogeographic relationships between the tectonic units and the application of geodynamic models. The post-Variscan “Alpidic” metallogenetic development of the Eastern Alps can be divided into an extension phase during Permian to Jurassic, and a compression phase starting in the Late Cretaceous. The formation of mineral deposits was controlled by a high geothermal gradient, fluid circulation along deep-crustal structures and suitable traps in Paleozoic and Mesozoic rocks. The formation of a heat dome underneath the passive continental margin of Pangaea by crustal thinning led to the formation of anatectic pegmatites and leucogranites from crustal melts in the bedrock of today`s Austroalpine nappes. Less than 1 % of the pegmatites are enriched in elements such as lithium, beryllium, tantalum or tin. By radiometric dating of garnet, cassiterite, columbite, spodumene and zircon, this phase can be bracketed to a period from 290 to 240 Ma. In the Triassic, pre-Variscan bedrocks as well as Upper Carboniferous to Lower Triassic clastic and evaporitic sediments were superimposed by very thick carbonate sequences on a facies-differentiated, extensive shelf at the margin of the Neo-Tethys. The high heat flow caused by persistent extension tectonics led to the circulation of saline formation waters from the Triassic sequence to the bedrock. These fluids were focused in deep-crustal fracture systems and led to the metasomatic replacement of carbonate rocks. Sm-Nd isotope dating documents the formation of magnesite and siderite in the Upper Triassic (230–208 Ma), occasionally also in the Permian. The radiometric dating of sphalerite from the Bleiberg-Kreuth deposit using Rb-Sr isotope analysis shows that the main phase of the formation of Austroalpine carbonate-hosted Pb-Zn ores in the stratigraphic levels of the Anisian and Carnian from saline, low-temperature fluids took place at the Triassic/Jurassic transition (about 200 Ma). In the Penninic Ocean (Alpine Tethys), small-scale pyrite-dominated „Kieserze” were formed during the Jurassic and Early Cretaceous, which are to be regarded as equivalents of volcanogenic massive sulphide deposits. In pelagic sediments of the Austroalpine and the Penninic realms, manganese-rich sediments were also deposited. In the Cretaceous there was a change from extension to compression tectonics with subduction of the Meliata Ocean and subsequent collision and nappe stacking in the Austroalpine, as well as the beginning subduction of the Alpine Tethys. At the Eoalpine peak of metamorphism (90 Ma), structure-controlled vein mineralization (Mitterberg/Hochkönig) and metasomatic deposits in carbonate rocks (siderite at Hüttenberg) were formed. Furthermore, sulphide ores were remobilized in higher metamorphic areas. In the course of the Neoalpine continent-continent collision and subsequent uplift and extrusion of large parts of the Eastern Alps, shear zone-hosted deposits such as the hematite deposit Waldenstein (approx. 46 Ma) in Austroalpine, and the “Tauern gold veins” (approx. 27 Ma) in Subpenninic and Penninic nappe systems were formed.

Blutdiamanten und Blutcoltan – der Handel mit Konfliktrohstoffen

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Im Rahmen der Initiative „Unclassified“ besteht ein Angebot der Montanuniversität, spannende und aktuelle Forschungsthemen in einem Onlineformat an die Schulen zu tragen. Die Anfragen werden über die Adresse info@unileoben.ac.at vom Büro für Öffentlichkeitsarbeit der Montanuniversität abgewickelt. Mag. Xenia Schnehen und Irene Fritz koordinieren und stellen den Kontakt mit den Vortragenden her. Der hier vorgestellte Vortrag behandelt die Problematik der Rohstoffproduktion in Entwicklungsländern und Krisenregionen. Er wurde online bereits an mehreren Schulen im Rahmen einer Schulstunde präsentiert und von Schülern und Lehrern positiv aufgenommen. Als Einstieg wird über den Bedarf und die Produktion von wichtigen mineralischen Rohstoffen weltweit, und auch in Österreich berichtet. Der weitere Fokus liegt dann auf der Rohstoffproduktion aus afrikanischen Ländern. Beworben wird der Vortrag auf der Homepage der Montanuniversität (https://starter.unileoben.ac.at/unclassified) mit folgendem Text: Bewaffnete Konflikte werden in vielen Entwicklungsländern durch Rohstoffhandel finanziert, allen voran mit Gold und Diamanten, aber auch mit Hochtechnologierohstoffen wie Coltan und Zinn, die für die Elektronikindustrie wichtig sind. Warum werden diese Rohstoffe gerade in solchen Ländern gefördert? Wie findet der Bergbau dort statt? Was kann man tun, um die Ausbeutung der Menschen und die verbreitete Kinderarbeit zu unterbinden? Solche Fragen werden im Vortrag des Geologen Frank Melcher diskutiert, der jahrelang in Krisenregionen Afrikas tätig war und mit der Entwicklung von „Fingerprints“ für Rohstoffe einen Weg zur Nachverfolgbarkeit aufzeigt. Zertifizierte Bergbauprodukte werden in unserer Gesellschaft immer wichtiger. Gleichzeitig steigt der Hunger nach Rohstoffen. Daher müssen gewaltige Anstrengungen unternommen werden, um den Bedarf unserer Gesellschaft durch ökologischen und sozial verträglichen Bergbau zu decken.

Enigmatic corundum-rich rock from the central Tauern Window: metabauxite in the Habach Group?

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A 60 kg block of a dark grey, hard, almost structureless sulphide-rich rock was found in the river bed of the Obersulzbach Valley near Hopffeldboden, Pinzgau, Venediger Alps (Salzburg, Austria). In this area, the prevalent Variscan granite gneisses of the Central Gneiss Supersuite are intercalated with metavolcanics (amphibolite, chlorite schist) and metasedimentary rocks (micaschist, graphitic phyllite) of likely pre-Variscan origin. They are attributed to the “Schieferhülle Nordrahmen” (“Lower Schist Cover”), correlated to the Habach Group. In this contribution, we provide a mineralogical and geochemical characterization of this unusual rock and speculate on its origin. Microscopic examination reveals abundant magnetite, hematite, pyrite and some chalcopyrite in a very finegrained non-foliated matrix, in which rare white mica flakes and aggregates could be unequivocally identified. Under the SEM, the fine matrix turned out to consist mainly of anhedral corundum of 30–50 µm grain size intergrown with green-blue pleochroic Fe-rich chloritoid (#Mg = 15–26) and less abundant light green chlorite with #Mg ranging from 40–50. White mica aggregates consist of intergrown margarite and paragonite and are often surrounded by large chloritoid crystals. Apatite is present throughout the rock, although grain size and abundance vary. Accessory phases include diaspore, epidote/allanite, zircon, and Ca-rich monazite. Oxide minerals mainly consist of magnetite and ilmenohematite. Uraninite and Nb-rich rutile (4–6 wt.-% Nb_2O_5) are subordinate. Sulphides postdate the oxide-silicate assemblage and mainly consist of pyrite and chalcopyrite, with rare molybdenite. Chemical analysis by wavelength-dispersive X-ray fluorescence spectroscopy on a fused disc reveals high contents of Al_2O_3 (51 wt.-%), Fe_2O_3 (29 wt.-%) und S (9.7 wt.-%), low SiO_2 (3.8 wt.-%), CaO (1.8 wt.-%), MgO (0.7 wt.-%), and K_2O and Na_2O. TiO_2 (3.9 wt.-%) and P_2O_5 (1.2 wt.-%) are severely enriched compared to typical crustal rocks. Among the trace elements, high contents of Zr, V, Nb, Cu and Ga are noteworthy, along with low Cr, Ni, Y and REE. The chemical composition resembles Si-depleted, Fe-rich bauxite. Compared to other metabauxites, the P content is extraordinarily high; abundant apatite in the rock appears to postdate the corundum assemblage. Apart from S, Fe, Cu and P, levels of minor and trace elements are within the ranges expected for bauxite. Trace elements concentrations, especially low Ni-Cr contents favour an origin from acidic precursor rocks. Chemical composition and mineralogy both strongly argue in favour of a bauxitic origin of the sample. The lack of marble in the Habach Group points to derivation from laterite bauxite or silicate bauxite, and low-Cr-Ni contents exclude an origin of the detritus from ophiolite rocks, but rather point to an acidic granitic source. Two options are to be discussed: (1) post-Variscan weathering of Variscan gneisses, most likely in the Lower Triassic, or (2) pre-Variscan weathering of older crustal rocks. Although metamorphosed paleoweathering horizons are known from several locations in the Tauern Window and the Austroalpine nappes, the corundum-rich boulder described in this contribution remains enigmatic and requires further field and laboratory studies.

The Weissensee – A natural carbonate mineral factory

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Freshwater lake settings can be used to follow the effects of climate change, like the increasing atmospheric temperature and CO_2 concentration. For instance, acidification of freshwater is challenging for many aquatic organisms and thus crucial for intact ecosystems. In order to evaluate the climate impact on a well-defined Austrian alpine region, the Weissensee freshwater lake in Carinthia (929 m a.s.l.) was selected for a site investigation and time series analysis to record and asses (i) seasonal hydrological and hydrochemical variations, (ii) potential long-term trends, (iii) mineralogical, chemical composition, and microstructures of modern sediments and (iv) seasonal distribution of stable hydrogen and oxygen isotopes of the water. The data set of the lake water indicates seasonal and site-specific effects whereas the long-term data reveal a significant trend of increasing surface water temperature in autumn and winter as well as rising concentrations of Na^+, Mg^{2+}, and Ca^{2+} ions within the last three decades. In contrast, no evidence regarding freshwater acidification due to elevated atmospheric CO_2 concentrations could be found. The modern Weissensee sediment mainly consists of the minerals calcite (low Mg-calcite) and dolomite with spatial differences from 1 to 96 wt.-%, which is caused by variable input of locally precipitated calcite and suspended dolomite from the catchment area. The authigenic lacustrine calcite is of particular interest, as constituting an important CO_2 sink. The nano- to microcrystalline calcite crystals in the Weissensee sediment are surrounded by extracellular polymeric substances, thus classified as lacustrine microbialites with substantial organomineralization. In some cases, a low percentage of aragonite, as a third carbonate mineral, hints towards its precipitation from the water column in early summer.

New approaches to predict top seal integrity of geological reservoirs: Case study examples from the Vienna Basin

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Seal rock integrity is not only an important success factor in hydrocarbon exploration but also highly relevant in a geological storage context. Top seal leakage may play a significant role in the preservation of accumulated fluids (e.g., primary oil and gas or injected storage fluids), but also the potential interaction of pore fluids with the seal rock (e.g., induced diagenesis by storage gases such as H_2 or CO_2). This work presents recent developments in the prediction of seal capacity and the detection of top seal leakage in the Miocene (Badenian to Pannonian) Vienna Basin infill. Different state-of-the-art characterization techniques such as micro-computed tomography, broad ion beam-scanning electron microscopy, gas physisorption with N_2, CO_2 and Ar, as well as nuclear magnetic resonance spectroscopy combined with core plug saturation experiments are introduced and their capabilities to visualize multi-scale changes in seal rock properties are discussed. Fluid Inclusion Chemostratigraphy was used for the first time as a geochemical tool for the detection of migration and/or diffusion through low-permeable top seals, and these results are critically reviewed based on complementary petrophysical and petrographical data as well as existing core descriptions and wireline log interpretations. Furthermore, a workflow for seal capacity prediction based on established normal compaction trends and resulting models for porosity, displacement pore throat radius and permeability is introduced and the major controlling factors for the estimated breakthrough pressures and corresponding maximum hydrocarbon column heights (e.g., facies and mineralogical changes, burial compaction) are outlined. Particularly, Badenian mudstone pore space characteristics show a considerable facies sensitivity closely linked to the respective well position related to paleo-delta or shoreline regions. These changes are illustrated based on results from advanced scanning electron microscopy-based petrography and image processing. Finally, first petrographic and geochemical evidence for a direct relationship between vertical hydrocarbon migration through top seals and induced diagenesis within these low-permeable layers (mainly calcite cementation) is provided. Based on the presented case study results, top seal leakage and vertical migration through semi-permeable mudstone layers have to be considered important fluid transport mechanisms besides the arguably dominant fault-controlled vertical migration.

Nanoindentation: A new workflow for spatially-resolved micromechanical investigations on sedimentary organic matter

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As a source for thermally generated oil and gas, sedimentary organic matter plays an important role in geoenergy-related research. Its pore structural and micromechanical properties need to be understood in order to predict matrix and fracture transport processes in organic matter-rich rocks including coals, which may serve as unconventional hydrocarbon and potential secondary gas storage (e.g., CO_2) reservoirs. This contribution introduces nanoindentation as a novel technique to obtain spatially-resolved micromechanical properties (e.g., hardness H and elastic modulus Er) at a micro- to nanometer length scale for both coals and organic-rich shales. A nanoindentation study on Carboniferous coals from the Ukrainian Donets Basin (vitrinite reflectance range from 0.62 to 1.47 %Rr) shows highly variable properties for the three different maceral groups (vitrinite, liptinite, inertinite). While inertinite H and Er are exclusively controlled by the conditions during primary inertinite formation (paleo-wildfire temperature), vitrinite and liptinite are affected by both primary depositional (e.g., sulphur content, mineral matter inclusions, primary pore structure) and secondary thermal maturation-related (e.g., bitumen generation) processes. A pore structural control on micromechanical properties of vitrinite is indicated by the correlation between Er and average nanopore diameters obtained by high-resolution transmission electron microscopy, which in some cases is obscured by pore occlusion by bitumen impregnations particularly at peak oil maturity (~0.9 %Rr). While nanoindentation of coals is relatively straight forward due to their organic richness and the easily identifiable maceral types, an improved approach was necessary to establish nanoindentation as a characterization tool for the finely dispersed organic matter in shales. An overmature sample set (vitrinite reflectance range of 1.33 to 2.23 %Rr) from the Lower Cretaceous Shahezi Formation in the Songliao Basin was selected in order to test for pore structural and resulting micromechanical changes of vitrinite and secondary pyrobitumen macerals. High-speed nanoindentation mapping was combined with multiple high-resolution imaging techniques and a new preparation approach by femtosecond laser treatment, and the results were analysed by k-means clustering in order to eliminate grain boundary and heterogeneity (e.g., mineral inclusion) effects. Adjusted for these influencing factors, a declining Er trend of organic matter with increasing thermal maturity is visible for samples up to 1.96 %Rr, at which point Er remains relatively constant with a slight indicated increase towards the overmature range arguably as an effect of severe compaction. The representative Er clusters determined for vitrinite and solid bitumen range significantly lower compared to previous nanoindentation studies on organic constituents in shales, and clearly show that nanoindentation mapping is capable of providing reliable micromechanical properties even for disseminated organic matter at a particle size in the range of micrometers. The established femtosecond laser marking technique enabled a comparative imaging study, which helped to explain outliers (e.g., due to indentation on cracks or at positions with poor surface quality) and systematically shifted clusters (e.g., areas near grain boundaries with harder mineral matter) identified by the machine learning algorithm.

Shale oil enrichment: Insights from combined organic geochemical, petrophysical and petrographical observations

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Shale oil produced directly from source rock reservoirs represents a valuable global energy resource. In this contribution data from lacustrine and marine source rocks of the Songliao and Junggar basins (China) and the Central Graben (Norwegian North Sea), as well as coals from the Ukrainian Donbas are presented to illustrate how both primary depositional and thermal maturation-related processes may affect the physical properties of the accumulated oil, as well as the storage and expulsion behaviour of the source rock. Shale oil accumulation in the lacustrine Lucaogou Formation of the Junggar Basin is characterized to a large degree by a complex reservoir architecture, leading to different accumulation mechanisms in the lower and upper members of the prolific source formation. Both members contain sand layers that may act as drainage layers for expulsed oil. Oil-source-correlation proves that in the lower member the oil accumulated in sandstone interlayers is sourced from the directly adjacent source rock, and density and viscosity are mainly controlled by the primary depositional setting (e.g., salinity variations and resulting change in primary bioproductivity) and source rock thermal maturity, as well as minor fractionation during expulsion. In contrast, in the upper member, secondary migration over longer distances into sandstone interlayers and resulting hydrocarbon fractionation and mixing are more important controlling factors for oil property distributions. In general, the expelled shale oil shows the highest density and viscosity at peak oil maturity of the source rock, as evidenced both from production data and from hydrous pyrolysis experiments conducted on the Locaogou Formation. The same characteristics could experimentally be proven for the lacustrine Qingshankou Formation in the Songliao Basin, where the amount of high-molecular weight bitumen (soluble part of the S2 peak from Rock-Eval pyrolysis) peaks together with both the amount of free hydrocarbons indicated by the Rock-Eval S1 peak, the total extractable organic matter, as well as the corresponding saturated vs. aromatic compound ratios. This interpreted maximum of shale oil in place at ~0.8 %Rr (oil peak) is followed by a sharp decline in all of the aforementioned parameters at slightly higher thermal maturity (0.9 %Rr). This may indicate the onset of hydrocarbon expulsion at > 0.8 %Rr, as well as a relatively good expulsion efficiency as observed also for the Lucaogou Formation in pyrolysis experiments. The moment of expulsion can also be traced by combined gas adsorption and scanning electron microscopy which indicates pore occlusion by pre-oil solid bitumen at the oil peak, and gradual opening of pores due to expulsion at advancing maturity. The gas storage and retention behaviour of the investigated shales may hence abruptly change with ongoing thermal maturation, as matrix pores are liberated from occluding hydrocarbons. Pore occlusion and changing physisorption capacity in response to the presence and molecular composition of in-situ solid bitumen is also visible in scanning electron microscopy and gas adsorption data from the terrestrially influenced, marine source rocks of the Mandal Formation in the Central Graben of the Norwegian North Sea, as well as similar pore structural results obtained from bituminous coals from the Ukrainian Donbas. The presented results highlight the complex enrichment and expulsion processes associated with shale oilplays.

Quantifying shear strain of a potential halite detachment below the Swiss Eastern Tabular Jura

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Middle Triassic evaporite successions encompassing anhydrite and halite of the so-called Zeglinge Formation (“Salzlager”) are known to form a major detachment along the floor thrust of the Jura fold-and-thrust belt in northern Switzerland (e.g., Jordan, 1990, Eclogae geologicae Helvetiae, 83, 525–542). The spatial distribution of these evaporites also extends north of the Jura Main Thrust that forms the northern limit of the range. This observation and the occurrence of regional folds north of the Jura Main Thrust guided the tectonic interpretation that a major detachment with some hundreds of meters thrust displacement also underlies the so-called `Vorfaltenzone`, a narrow zone between the autochthonous Tabular Jura in the Northwest and the allochtonous Folded Jura to the South (“thin-skinned model”). A competing, yet unpublished interpretation of the folds north of the Jura Main Thrust, however, infers a thick-skinned origin of these structures, i.e., resulting from the re-activation Paleozoic basement faults of the Constance-Frick Trough (“thick-skinned model”; see Madritsch et al., 2018, Tectonics 10.1029/2017TC004945 for a discussion of regional tectonics). The National Cooperative for the Disposal of Radioactive Waste (NAGRA) recently has drilled through the salt succession of the Zeglingen Formation at four locations within the “Vorfaltenzone”. To test the competing deformation models for this tectonic domain, cores from these Zeglingen evaporites are analyzed with regards of structures which can be used for quantifying the shear strain of the drilled anhydrite and halite. Cores are oriented allowing to determine the true orientation of structures and provide continuous sections through the potential evaporitic detachment. Both macroscopic and microscopic observations are used to develop a strain profile through the evaporites. Results show that large parts of the up to about 30 m thick halite sections and most of the anhydrite units are virtually undeformed showing up to 10 cm sized crystals of rock salt and stylolithic bedding. Sheared and mylonitic halite is limited to several up to about 1 m thick intervals. Orientations of foliation, stretching lineation, elongated (sigmoidal) grains, shear bands and winged inclusions prove polyphase kinematics with different transport directions arguing against a continuous high-strain detachment. The preliminary assessment will be completed by quantifications of the shear strain in mylonitic halite layers using winged inclusions (Grasemann et al., 2015, Journal of Structural Geology, 70, 78–94).

The stratotype of the Gutenstein Formation

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New biostratigraphic data derived from the stratotype of the Gutenstein Formation at the village Gutenstein (Lower Austria) help to solve some long-standing problems about the stratigraphy of the Anisian stage within the eastern part of the Northern Calcareous Alps (NCA). The mainly stratigraphically definable lower lithostratigraphic boundary of the Gutenstein Formation to the underlying Reichenhall Formation can be defined with help of the “Reichenhall fauna”, described by Bittner (1897) and new microfacial data coming from the Anisian rauwackes. Moreover, a detailed lithostratigraphic and microfacial definition of the Gutenstein Formation as mainly thin and planar bedded, black colored, sometimes fine-bedded limestone (dolostone) and radiolarian bearing, black colored mud- to wackestone, mostly containing some fine crinoid debris, is nominated. Additionally, upsection, a gradual change to an upper (Pelsonian) member with nodular bedding planes and brachiopod-, crinoid- and ammonite accumulations, can be described. The depositional environment of the Gutenstein Formation is considered to be that of an outer carbonate ramp deposit, with a shallowing upward trend to the mid- and inner carbonate ramp deposits of the Annaberg- and Steinalm Formations. The approximate interval of the Anisian/Ladinian boundary within the type section of Gutenstein is determined with help of new fossil findings. Based on distinct lithological differences, which appear within the Gutenstein Formation as part of a basin-like sedimentary succession at Großreifling (Styria), at Innerfahrafeld (elevation Fuchsriegel, Lower Austria) or on mount Kasberg at Grünau (Upper Austria), a subdivision of the whole Gutenstein Formation into a lower, so far unnamed member, and an upper Kasberg Member (= upper Gutenstein Formation), is proposed. A complete lithostratigraphic definition of the Gutenstein Formation, its members and adjoining stratigraphic units is still in progress.

MURmap – Holistic geochemical tracking of elements and their sources in the Mur/Mura River Catchment

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In the project MURmap, new scientific knowledge of the environmental geochemistry of conventional and modern inorganic pollutants is obtained on a European river catchment on the example of the Mur/Mura River. In the following, a holistic approach towards cross-border geochemical elemental and isotopic tracking of the fluvial system and its tributaries will be carried out. The project aims at the determination of (1) natural geochemical background of the catchment area, (2) historical and recent anthropogenic sources of chemical elements, (3) interaction of chemical elements between solid and liquid phases in different physical and chemical water conditions, (4) individual particles as carriers of specific pollutants, (5) differences in the elemental composition of water and sediments in high, medium and low water regime (6) the potential contamination and baseline levels of emerging modern high-technology pollutants, (7) chemical and isotopic composition (based on XRF and MC ICP-MS) of drainage systems, including drainage waters and drainage sediments and (8) at the establishment of sampling, analytical and data curation protocols for such a complex dataset. The obtained data and information will be (9) merged into an easily understandable set of ecological indicators and maps. In three campaigns (May 2022, August 2022 and February 2023) water samples, suspended particulate matter, and alluvial and stream sediment samples are taken and processed to geochemically and mineralogically characterize the Mur catchment area. First sample analyses taken in 2022 at selected sites show already a wide-ranging occurrence and variation in elements and are discussed along with geological background data and historical land use within the area.

Drowning of the Ravni carbonate ramp and the overlying late Middle Anisian Bulog Formation in the Seljani area, Montenegro, Dinarides

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Triassic sediments cover more than the half of the total territory of Montenegro. Most of them are shallow-water or deep-water carbonates. Dating by means of conodonts will result in a better picture of the paleogeographic, lithological-stratigraphic and tectonic structure of the terrain. In the village Seljani (Plužine) an Anisian section – Ravni Formation and overlying Bulog Formation – was investigated in respect to their exact biostratigraphic age by conodont dating and depositional environment using microfacies analysis. In the Ravni Formation at the Seljani locality appear two generations of neptunian dykes filled with red nodular limestone. In the investigated profile the shallow-water Ravni Formation contains in the upper part layers consisting of calcareous algae, and crinoid-rich layers, both overlain by a condensed layer of red nodular limestone (Bulog Formation) with deep-water organisms, e.g., ammonoids and conodonts, and shallow-water organisms (foraminifers). Litho- and microfacies clearly indicate a change in the depositional environment and the drowning of the Ravni carbonate ramp. The age of the two generations of neptunian dykes filled with red nodular limestones correspond to the evolution of the overlying Bulog Limestone succession. Within the older generation of fissure fillings (predominantly filament wackestones), crosscut by younger fissures (filament packstones with volcanic clasts), the following conodonts were determined: A) *Pg. bifurcata*, *Pg. hanbulogi*, *Ng. cornuta*, and B) *Pg. excelsa*, *Pg. trammeri*, *Gladigondolella*-ME and *Gladigondolella tethydis*. This mixed fauna indicates two different ages within one sample, namely the late Pelson-early Illyrian and the late Illyrian. In the younger fissure generation with brachiopods following conodonts were found: *Pg. excelsa*, *Pg. szaboi*, *Pg. trammeri*, and *Gladigondolella tethydis* indicating a late Illyrian age. The older type of the Bulog Formation above the Ravni Formation shows the following evolution: Directly above the Ravni Formation the radiolarian wackestones of the Bulog Formation contain few foraminifera beside ammonoids, filaments and conodonts. This 5 cm thick bed contains *Pg. bifurcata, Pg. bulgarica, Pg. hanbulogi, Pg. szaboi* (from fissure infilling), *Ng. cornuta*, and *Gladigondolella tethydis* indicating a late Pelsonian and an early Illyrian age, i.e. condensation. Higher up in the section *Ng. cornuta, Pg. praeszaboi, Gladigondolella tethydis* indicate an early to middle Illyrian age. The younger (late Illyrian) type of the Bulog Limestone with intercalated oligomictic breccia layers contains e.g., radiolarians, filaments, and volcanic grains, but is in the upper parts strongly recrystallized and siliceous. In the lowermost part this late Illyrian Bulog Limestone contains *Pg. trammeri* and *Ng. cornuta*. Higher up *Pg. excelsa, Pg. trammeri, Gladigondolella tethydis* and *Gladigondolella*-ME prove a late Illyrian to Fassanian age. In the highest part of the more and more recrystallized and siliceous Bulog succession a similar age is proven by the occurrence of *Pg. excelsa* and *Pg. trammeri*. The Bulog limestone evolution and the fissure infillings reflect two phases of tectonic extension and generally deepening of the depositional environment. The first event with the drowning of the Ravni carbonate ramp (Steinalm carbonate ramp in the Eastern Alps) is related to the onset of the opening of the Neo-Tethys and the second extensional event can be correlated with the intense volcanic activity during Late Illyrian times. It can be concluded that the Middle-Late Anisian depositional history due to the opening of the Neo-Tethys is contemporaneous in the Dinarides and in the Eastern Alps.

Explosive volcanism as precursor of the Julian "Carnica" Event in northern Montenegro (Durmitor Mega-Unit)

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The demise of the Wetterstein Carbonate Platform (WCP) evolution s. str. (latest Ladinian to earliest Julian) in the Western Tethys Realm is discussed controversially. In the ALCAPA region of the Western Tethys Realm and the Southern Alps the WCP shows a drowning related to the Lunz Event (Reingraben Event, Mid-Carnian Pluvial Episode or Mid-Carnian Wet Intermezzo). The reasons for this turnover are controversially discussed. However, prior to the drowning of the WCP with siliciclastics the platform emerged due to a sea-level drop, and the underfilled accomodation space between the platform areas became restricted deep lagoonal areas with deposition of in parts organic-rich siliceous limestones (Carnica Event), followed by the deposition of fine grained siliciclastics (Reingraben claystones). Whereas in the northwestern part of the Western Tethys Realm including the Outer Dinarides in Croatia, these siliciclastics were widespread deposited, they are practically unknown in the Inner Dinarides to Hellenides. In contrast to the ALCAPA region in the Dinarides/Hellenides a long-lasting stratigraphic gap is common. Carbonate deposition started again earliest in the Late Carnian after the demise and uplift of the WCP in the Julian. However, recently fine-grained Mid-Carnian siliciclastics deposited in an underfilled deep-lagoonal basin between the Wetterstein Carbonate Platform in the Inner Dinarides, namely between the Drina-Ivanjica Mega-Unit to the east and the Durmitor Mega-Unit to the west, fine grained siliceous siliciclastics were described (Džegeruša Formation). From the Durmitor Mega-Unit in northern Montenegro, near the village Pliješevina the contact between basinal limestones above the slope limestones of the WCP is characterized by the change of grey filament- and radiolarian-rich biomicrites (Cordevolian dated by *Gladigondolella malayensis* and *Gladigondolella*-ME, *Paragondolella polygnathiformis, Neocavitella* sp. juv. and *Paragondolella tadpole*) to siliceous claystones, black radiolarites and silicified volcanic ashes. This roughly 1.5 to 2 m thick series is overlain by medium grey filament bearing biomicrites with *Mazzaella carnica, P. polygnathiformis, P. auriformis*, and *N. cavitata*. These results clearly evidence volcanic activity predating the Carnica Event. In contrast to the Late Illyrian to Ladinian volcanism this "Mid-Carnian" volcanism is practically unknown. To characterize the silicified volcanic ashes, XRD analysis was performed. The Late Illyrian volcanic ashes contain calcite as main component as well as smectite group clays (beidellite, nontronite), microcline, and subordinate mixed layer clays. In contrast to the volcanic ashes of the Late Illyrian the metabentonite of the Mid-Carnian is composed of biogenic quartz, mica-group minerals, smectite-group clays (nontronite), palygorskite/sepiolite and mixed layer clays. The Mid-Carnian metabentonite contains no carbonate. Based on the mineralogical phases a clear difference in the composition of the volcanic ashes can be recognized. A sea-level drop at the beginning of the Julian followed by volcanic activity led to a rapid decrease of carbonate production and the demise of the WCP evolution. The deposition of siliceous and in parts organic-rich limestones (Carnica Event), also improved by the occurrence of glauconite in the XRD analysis, predates the final drowning (ALCAPA) or the uplift (Dinarides) of the WCP.

Porosity – depth trends for Vienna Basin mudstones: Validation of broad ion beam – scanning electron microscopy as a seal prediction tool

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In order to implement new forms of energy, to transform energy systems accordingly and to create a long-term contribution to the energy transition, alternatives to fossil fuels such as hydrogen are necessary. To enable the safe long-term underground storage of such new energy carriers but also the potential sequestration of CO_2 quickly on a large scale, geological structures such as depleted hydrocarbon reservoirs or deep aquifers may be a feasible solution. However, the use of such "geological containers" for secondary storage demands an evaluation of the regional seal rock quality. In this study, 14 Miocene (Badenian, Sarmatian, Pannonian) seal rock samples of the Vienna Basin from 9 different wells, covering a depth range of 721.5–3,217.5 m, were investigated with respect to porosity depth trends and resulting estimated seal capacity. The main target was to validate broad ion beam – scanning electron microscopy (BIB-SEM) as a tool to derive reliable pore structural data for seal quality prediction. For this, image-segmented porosity and pore size distributions were collected from multiple 2D high-resolution BIB-SEM maps with representative imaging areas of ~40,000 µm² for each individual sample. These pore characteristics were then correlated with porosity data and calculated theoretical maximum hydrocarbon column heights derived from mercury intrusion porosimetry (MICP) and He-pycnometry. Furthermore, the image-based porosity characteristics were compared with bulk mineralogical compositions from X-ray diffraction. The BIB-SEM data reveal porosity values ranging from 1.7–14.7 vol.-% for the investigated samples. Despite considerably lower absolute porosity values (BIB-SEM is limited to pore sizes > 30 nm), the image-based porosity values show a close correlation with the corresponding MICP (R^2 = 0.87) and He (R^2 = 0.87) porosity values, as well as clear decreasing depth trend (R^2 = 0.91). The total BIB-SEM porosity shows a power-law correlation with the calculated maximum hydrocarbon column heights (R2 = 0.82); furthermore, the mean pore diameter derived from BIB-SEM pore distributions shows a weak trend with the corresponding displacement pore throat diameter derived from MICP capillary pressure curves (R^2 = 0.42). The porosity values as well as the pore geometries seem to be unaffected by the quartz and total clay mineral content of the samples, however a compaction influence on pore shapes indicated by a depth trend of increasing pore aspect ratios (as well as a weak decreasing trend of average pore circularity) can be observed. In summary, the imaging results confirm that BIB-SEM can be used as a complementary porosimetry technique for seal quality estimation. Furthermore, the results show that mudstone porosity and resulting estimated seal capacity follow a porosity depth trend matching previous normal compaction trend models. The generated pore structural data set may serve as an additional calibration tool for future seal quality models in the Vienna Basin.

Fossil fuels – or: There's life in the old dogs yet, isn't it?

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Shale gas in the deepness of the Vienna Basin – an obscure idea to satisfy Austria's need of natural gas for decades or just a drowning man's rather desperate clutch at a straw? Interestingly, this question is not owing to results of scientific research, it is based upon some people's memories back to 2012 when OMV was planning such research but was abruptly prevented from drilling a test well by local, regional and federal politicians and self-appointed activists. After wood and coal, petroleum has become society's fuel of choice over the last one and a half centuries. The petroleum industry has been remarkably successful in finding oil reserves, producing them and bringing them to the market. This success has powered tremendous global economic growth and unprecedented drives in living this conduct around the world. Technology and its progress have been and will be critical to satisfy our ongoing demand for petroleum products and the oil and gas industry has used to be among the top technology driven industries worldwide, right after military and space industry. In light of global warming, energy transition has become a main terminus with partly very ambitious targets for timing and development / utilization of renewable versus fossil energy sources. Unfortunately (or even tentatively?), consequences of this transition for and its impact on the environment and our future living conditions are in this discussion very often ignored. To say it with Scott Tinker, director of the Bureau of Economic Geology in Austin, Texas: there are two important reasons, why the often-proposed switch from dirty coal and oil to clean and renewable solar and wind contradicts all laws of physics: they are not renewable and they are not clean. Sure, during non-cloudy days and windy times, wind and sun can be captured and turned into electricity. But because the amount of energy is not "dense" it takes scads of land and collectors – solar panels and wind turbines – to capture it. Further, it also takes oodles of batteries to back up intermittent solar and wind to keep everything running uninterrupted. There is also replacement. The panels, turbines and batteries wear out after 10 to 20 years, and the metals, chemicals and toxic materials required to make them must be constantly mined, manufactured and disposed of in landfills. Coupled with some CO_2 emissions associated with those processes, solar and wind are neither renewable nor clean. During recent years, giant oil and gas fields around the globe have been discovered. Rystad Energy calculates that to meet the global cumulative demand over the next 30 years, undeveloped and undiscovered resources totaling 313 billion barrels of oil need to be added to currently producing assets. To match this requirement, exploration programs will have to discover a worthy-to-develop resource of 139 billion new barrels of liquids by 2050. Renewable energy sources will contribute a growing share to satisfy the world 's energy hunger, BUT they will, at least in foreseeable time, not be able to cover the full and growing energy demand especially that of energy-intensive industries. Most petroleum companies support and actively pursue steps in this diversification – they see here a number of complementary business opportunities where application of their petroleum-based experience and technologies provides additional income and employment for their professional staff.

The temporal evolution of seismicity and variability of Gutenberg-Richter b-values along the Vienna Basin Transfer Fault System

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The Vienna Basin Transfer Fault System (VBTFS) is the most active fault in the region between the Eastern Alps, the western Carpathians and the Pannonian Basin. The spatial and temporal distribution of earthquakes along the fault shows a heterogeneous pattern including a long-time decay of seismicity at the northern part of the VBTFS, which was interpreted to result from a long aftershock sequence subsequent to the 1906 Dobrá Voda earthquake (M = 5.7). In this paper we investigate if other strands of the VBTFS display similar long-term declines of seismicity that might indicate long aftershock sequences following strong, yet unrecorded, earthquakes in historical times. In order to analyse the distribution of seismicity, the VBTFS is divided into arbitrary segments of about 50 km length each. The segments are chosen to overlap each other to avoid missing information from neighbouring segments due to arbitrarily selected segment boundaries. For each segment we analyse the temporal evolution of seismicity and calculate the parameters of the corresponding Gutenberg-Richter (GR) relation. The temporal seismicity patterns revealed from the segments covering the Dobrá Voda area confirm the protracted aftershock sequence following the 1906 earthquake. All but one of the other segments do not show temporal changes of seismicity comparable to the long-term Dobrá Voda aftershock sequence. Seismicity patterns, however, include short-term Omori-type aftershocks following moderate earthquakes such as the 2000 Ebreichsdorf earthquake (M = 4.8). The segment covering the SW tip of the VBTFS revealed a 200 years long gradual decrease of the largest observed magnitudes starting with the 1794 Leoben (M = 4.7) earthquake. The 1794 event is the oldest earthquake listed in the catalogue for the region under consideration. It therefore remains open if the recorded decay of seismicity results from the 1797 event, or a stronger earthquake before that time. The latter is corroborated by the low magnitude of the 1794 earthquake which would typically not be considered to cause long aftershock sequences. GR a- and b-values, calculated for the individual segments, vary significantly along the VBTFS. Values range from 0.47 to 0.72 (b-values) and 0.81 to 2.08 (a-values), respectively. Data show a significant coincidence of the lowest b-values with fault segments with large seismic slip deficits and very low seismicity in the last about 300 years. These parts of the VBTFS were previously interpreted as “locked” fault segments which have a significant potential to release future strong earthquakes, in spite of the fact that historical and instrumentally recorded seismicity is very low. We find this interpretation corroborated by the low b-values that suggest high differential stresses for these fault segments.

Mono-energetic micro-computed tomography (µCT): A reliable potential alternative to mineral investigation of formation rock

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Traditional mineralogical investigations (namely XRD and SEM) are very useful; however, they are not only time consuming and expensive but also destructive. The artifacts introduced to the samples during the preparation phase cannot be ignored neither. Application of µCT is well known to the oil and gas industry with regard to core analysis studies, formation damage quantification and fishing expedition. However, in the former cases its application is limited to Dual energy CT scanning (DECT) since the material differentiation demands calibration of the density field (that is done traditionally using more than mono-energetic X-ray beam) which is obviously more expensive and more time consuming than mono-energetic scanning. In this study we have developed a database of mineral compositions of sedimentary formation rocks (using mineral investigation + µCT imaging). The database was then used to develop a mathematical model to correlate the pixel intensity into density (histogram segmentation <-> density field). We have seen promising results in quantitative measurement of mineral compositions using mono-energetic µCT and we are currently working further to develop morphological and topological factors as extra criterion of verifiability of the model. This will further improve the model accuracy as well.

Sediment deposition, regional uplift and local normal faulting recorded in the Danube terrace staircase of Vienna

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Quaternary landscape evolution in the Vienna Basin is controlled the climate related sediment aggradation/erosion of the Danube, local normal faulting, and regional uplift. Glacial-interglacial climate dynamics highly influence the mode and amount of sediment transport. Within the extensional structure of the Vienna Basin the highest vertical subsidence focuses narrow Middle-Pleistocene sub-basins. Outside the major Miocene Vienna Basin sidewall faults, normal faults are slow or inactive during the Quaternary. In these areas regional uplift is high enough to form terraces. In case regional uplift compensates local subsidence, complex terrace levels develop caused by rate change over time (i.e. phases of tectonic activity vs. quiescence). Local normal faulting imposed by regional uplift is apparent within the city of Vienna. Vienna is crosscut by prominent normal faults, the Leopoldsdorfer Fault System (LFS), with highest subsidence during the Miocene when it offset the alpine basement by around 4,500 m. At the surface, the western side of the LFS is characterized by a well-developed terrace staircase that is missing at the eastern side. Quaternary faulting along the LFS has been previously proposed. Here we analyze the dynamics of landscape evolution and include stream behaviour, normal faulting, and uplift into a consistent picture covering the time interval between the Late Pliocene and Early Pleistocene. In a multi-methodological approach, involving terrestrial cosmogenic nuclide dating, geophysical (ERT) prospection, multiple drill-log and sedimentological analyses, we investigate how regional uplift and local subsidence along the Vienna terrace staircase affect the geomorphology over the last ca. 2.5 Ma resulting in today's landscape. We propose that the vertical movement and different slip rates over time, first result in sediment preservation trough local subsidence and later in preservation through uplift and inversion.

Numerical ages of Paleo-Danube sediments at the Vienna Gate quantify Quaternary uplift

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The Vienna Gate marks the transition of the Danube's alluvial plain in the west (Tullnerfeld) into the extensional structure of the Vienna Basin. At this border, the Danube flows on top of a small (c. 2 km) segment of Penninic Flysch units before it enters the Vienna Basin to the east. Uplift is documented by fluvial terrace deposits at elevated positions located at about 15–35 m above the recent Danube riverbed. To quantify local uplift rates inside and outside of the Vienna Basin two locations close to the Vienna Gate were sampled for cosmogenic nuclide extraction, numerical age calculation, and uplift/incision rate calculation. Klosterneuburg is the western site and thus outside of the Vienna Basin Bounding Fault. Fluvial gravel was temporarily exposed in a construction pit. Fluvial gravel and cobbles of Seyring are located within the Vienna basin and are accessible in an active quarry. Sampling points are covered by loess (Seyring) or loess deposits are exposed close by (Klosterneuburg). Therefore, a varying thickness of cover sediments over time is highly likely, in particular for ages going back two or more glacial cycles. Consequently, the sampling strategy was to retrieve several samples at each location to calculate an isochron age using the pair of cosmogenically produced nuclides ^{26}Al and ^{10}Be. During this investigation, 16 quartz cobbles were processed. At Seyring cosmogenic nuclide concentrations indicate large scale sediment reworking. For the sampling point at Klosterneuburg, a depositional age and incision/uplift rate could be calculated using the isochron approach.

Formation of intermediate decomposition products (PAHs) during methane pyrolysis in a liquid metal bubble column reactor

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To counteract the progress of climate change, it is necessary to minimize CO_2 emissions by further developing the energy system. Besides established hydrogen consumers in metallurgy such as the production of molybdenum and tungsten powder from their oxides, the iron and steel industry among others is now also considering the increased use of hydrogen as an energy carrier and reducing agent. With this background, the production of hydrogen must be massively expanded and further developed to meet the increasing demand in metallurgy and other energy-intensive industries. Nowadays, nearly 96 % of the global hydrogen production comes from Steam Methane Reforming (SMR) and other processes based on fossil raw materials at an environmental burden of about 10 t CO_2 per t H_2, accelerating the consequences of global warming. A promising path to produce clean hydrogen is via methane pyrolysis using molten metals. Compared to SMR, significant less CO_2 is produced due to conversion of methane into hydrogen and solid carbon, making this route more sustainable to generate hydrogen. Solid carbon can be further used for different applications, like for agricultural purposes, where the carbon must be very pure without contaminants (e.g., polycyclic aromatic hydrocarbons (PAHs)). Within the scope of this work, a liquid metal bubble column reactor at the Chair of Nonferrous Metallurgy of the Montanuniversität Leoben is improved with the aim to define the process engineering challenges and to find solutions for them. During methane pyrolysis a number of different hydrocarbons, including C_2-, C_6- hydrocarbons or PAHs, are formed next to H_2 and undecomposed CH_4. The different hydrocarbons are found both in the exhaust gas system and in the produced carbon, which is undesirable mainly because of their toxic properties. The condensates produced in the test set-up as well as the solid fractions are analysed for these formed products in order to build up a better understanding in the process of pyrolysis and to force the prevention of the formation of these PAHs. Temperature and process duration in particular influence the formation of the gaseous main components H_2 and CH_4 and the intermediate products of methane pyrolysis. The most abundant compounds of PAHs in all samples are built up of 4 aromatic rings (e.g., pyrene) followed by compounds consisting of 3 aromatic rings (e.g., anthracene). Interestingly, the amounts of PAHs are much lower if the molten metal is covered with a carbon layer. The development of a suitable process and reactor design in laboratory scale as well as the stepwise upscale to pilot scale is crucial for a full understanding of the interaction of all process parameters at different reactor sizes, gas injection systems and continuous product discharge.

Invisible metals for a green future: Au associated critical elements in historic mining districts Murtal (Styria)

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Green technologies require metals like antimony, bismuth, cobalt, lithium, platinum group elements (PGEs), thallium, tantalum, tungsten and many others that are rarely mined in Europe. The transition to renewable energy production is leading to a massive increase in the demand for these ‘green’ metals. One of the pillars of EU raw policy is to foster production from local sources of these raw materials, in order to support and revive the mining industry in Europe, as well as to make the EUs climate future more self-reliant. Recent work has shown that gold and a sub-group of critical metals (hereafter referred to as precious metal associated critical metals or PMaCMs) can occur trapped within sulfide minerals often in invisible form. This previously overlooked source of precious metals and PMaCMs holds much promise for a ready source of precious metals within the EU. Our study is part of a larger project investigating the potential of historic mine tailings in Styria, as a possible source of those metals. We will present initial results from the tailings piles of three historical gold mining districts in Upper Styria, i.e. Flatschach, Pusterwald and Kothgraben. They are mesothermal vein type deposits, occurring in medium to high-grade metamorphic Austroalpine units and their mines were operated, on and off, from the 15th century up to the early 20th century. The primary focus of our work is to determine in which quantities PMaCMs are found within these deposits (using whole rock geochemistry) and to quantify their abundance. Not all metals in these deposits are visible with the optical microscope or electron microscope techniques (EPMA, SEM), and we report the occurrence of invisible gold within arsenic rich pyrite from at least one of the three deposits (Flatschach). Ongoing work is focusing on other sulfides in these deposits potentially hosting gold and PMaCMs (using LA-ICP-MS and EPMA). Atom probe tomography will be applied to characterize the atomic-scale link between arsenic (and other minor elements), gold, and PMaCMs. Additionally, we plan to constrain the timing of ore formation and to investigate the trace elemental signature of the ore minerals to determine if there is a geochemical and/or temporal link between these deposits that occur in comparable geological settings. EPMA and LA-ICP-MS techniques will be used to determine the trace elemental signature and critical metal content of the ore minerals. We will also be doing U-Pb dating of calcite, which is a rather novel method for dating this type of mineralized veins.

Mineralchemische Provenienzuntersuchungen an Fahlerzen am prähistorischen Verhüttungsareal Kundl (Unterinntal, Tirol)

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Zwischen 2018 und 2019 fand in Kundl (Bezirk Kufstein) unter der Leitung der Firma Talpa GnbR die bislang größte urgeschichtliche Flächengrabung Nordtirols nach modernen Standards statt. Auf einem rund 11.600 m^2 großem Areal in der Schottergrube Wimpissinger wurden Nutzungshorizonte aus dem 1. Jahrtausend v. Chr. freigelegt. Das ausgegrabene Werkareal bietet einen einzigartigen großflächigen Einblick in die Arbeitsschritte zwischen Bergbau und Metallproduktion. Die Nutzungsphasen dieses Werkareals reichen mindestens von der späten Bronzezeit bis in die späte Eisenzeit, also den Zeitraum, in dem sich der epochale Wandel mit dem Niedergang der Kupferproduktion und dem Aufschwung der Eisenmetallurgie vollzog. Um Kupfer oder Eisen aus den entsprechenden Erzen zu erzeugen, sind mehrere Arbeitsschritte notwendig, die in der Montanarchäologie üblicherweise nach dem Konzept der chaîne opératoire untersucht werden. Dies beinhaltet die vollständige mineralogische Charakterisierung sämtlicher Werkzeuge (v.a. Stein- und Metallgeräte), der metallurgischen Ausgangs-, Abfall-, Zwischen- und Endprodukte sowie der Fertigprodukte. In den bronzezeitlichen Blasenschlacken wurden Kupfertröpchen mittels Elektronenstrahl Mikrosonde untersucht. Die hohen As und Sb Gehalte in den Kupfertropfen weisen eindeutig auf die Verhüttung von Fahlerzen hin. In den metallurgischen Ausgangsmaterialien im Ausgrabungsbefund fanden sich Fahlerzbruchstücke. Bezüglich der Herkunft der verwendeten Erze für die bronzezeitliche Kupfermetallurgie finden im Zuge eines Doc-Teams der ÖAW umfassende mineralchemische Untersuchungen an den Fahlerzen von mehr als 10 Lagerstätten im Umkreis von Kundl, als auch aus verschiedenen tektonischen Einheiten in den westlichen Ostalpen statt. Erste Untersuchungen bezüglich der As, Sb, Cu, Zn und Fe Gehalte der Fahlerze ergaben bisher noch keine eindeutigen Hinweise auf die geographische Herkunft der Erzbruchstücke. Im Zuge erster Untersuchungen wurden bereits Analysen mittels Elektronenstrahlmikrosonde an Fahlerzen, welche im Siedlungskontext gefunden wurden, vorgenommen. Dabei zeigte sich eine homogene Zusammensetzung der Fahlerze mit 18,52 bis 20,41 Gew.-% Sb und 6,62 bis 8,04 Gew.-% As. Die Tetrahedrit-Komponente (XSb*100) liegt zwischen 59 und 63 %. Der Zn-Gehalt liegt durchschnittlich bei 1,25 Gew.-% und der Fe-Gehalt bei 3,94 Gew.-%. Ag und Hg wurden in Spuren detektiert, während Bismut unterhalb der Nachweisgrenze liegt. Im Vergleich zu bereits publizierten Daten von Fahlerzen aus dem FZ HiMAT liegt keine exakte Übereinstimmung zu bekannten Fahlerz-Lagerstätten vor. Am ehesten korrelieren die Zusammensetzungen der Kundler Fahlerze mit den Fahlerzen aus Schwaz, jedoch gibt es einen signifikanten Unterschied im Fe/Zn-Gehalt. Der ÖAW wird für die finanzielle Unterstützung des Doc-Teams gedankt.

Mikrocomputertomographische Untersuchungen an Blasen- und Plattenschlacken aus dem prähistorischen Verhüttungsplatz Kundl (Unterinntal, Tirol)

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Schlacke, die im Zuge von prähistorischen metallurgischen Prozessen angefallen ist, stellt eine sehr wichtige Informationsquelle für die Rekonstruktion des bronzezeitlichen Verhüttungsprozesses dar. Die prähistorischen metallurgischen Tätigkeiten werden im Zuge eines Doc-Teams der ÖAW untersucht. Durch die Analyse der mineralogischen und mineralchemischen Zusammensetzung sowie des räumlichen Aufbaus der Schlacken, lassen sich Rückschlüsse auf das verwendete Material und Verfahren herleiten. Dabei ist die chemische als auch räumliche Untersuchung von Einschlüssen von Kupfertropfen und Kupferstein entscheidend. Eine innovative Methode, um die räumliche Verteilung und Häufigkeit von Kupfertropfen innerhalb der Schlacke auflösen zu können, ist die Mikrocomputertomographie. Diese Methode erlaubt aufgrund der Dichteunterschiede eine visuelle Darstellung ausgewählter Phasen im untersuchten Objekt. Dies betrifft vor allem Metalltröpfchen in der silikatischen Matrix der Schlacken, deren Gehalt quantifiziert werden kann, um festzustellen, wieviel Metall noch in der Schlacke vorhanden ist. Dies gibt wichtige Auskunft über den Extraktionsgrad und somit die Effizienz des Verhüttungsprozesses. Der Fundplatz Kundl ist zum einen durch die zeitliche Diversität der Schlacken-Funde (Bronzezeit bis Eisenzeit) ein ideales Pilotprojekt für Untersuchungen mittels Mikrocomputertomographie, da dadurch die Verbesserung des Produktionsprozesses von Kupfer als Funktion der Zeit nachvollzogen werden kann. Aus verschiedenen Horizonten wurden sowohl Früh-, als auch Mittel- und Spätbronzezeitliche Schlackenfunde ergraben. Weiterhin gibt es innerhalb der Horizonte Proben sämtlicher Schlacke-Kategorien (Blasenschlacke, Plattenschlacke, Schlackensand und Ofenschlacke) welche die verschiedenen Arbeitsschritte konserviert haben. Für erste Untersuchungen wurden 5 Schlackeproben (4 Blasenschlacken und 1 Plattenschlacke) mittels Mikrocomputertomographie sowie Mikro-Röntgenfluoreszenz untersucht. Die ersten Ergebnisse zeigen eine viel stärkere Anhäufung von Kupfertröpfchen in den älteren Blasenschlacken im Vergleich zur Plattenschlacke. Dies ist ein eindeutiges Indiz für die zeitliche Verbesserung der Kupferextraktion im Zuge des Verhüttungsprozesses. Erste Auswertungen zeigen bereits deutliche Unterschiede zwischen den einzelnen Schlacketypen. Während die Blasenschlacke deutlich mehr und größere Kupfertröpfchen eingeschlossen hat, zeigt die Plattenschlacke deutlich geringere Durchmesser der Kupfertröpfchen. Auch differenziert der Kupfergehalt entlang der zeitlichen Achse. Die Schlackeproben aus der frühen Bronzezeit enthalten im Vergleich zu Schlackeproben aus der späten Bronzezeit deutlich mehr Einschlüsse von Metalltröpfchen. Dies lässt bereits erste Rückschlüsse auf die Effizienz des Verhüttungsprozesses bzw. die Verbesserung der Kupferproduktion innerhalb der Bronzezeit zu. Der ÖAW wird für die finanzielle Unterstützung des Doc-Teams gedankt.

Paleoseismoloy of the Seyring Fault in the Vienna Basin (Austria)

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Active tectonics along the Vienna Basin Transfer Fault (VBTF) has been studied thoroughly in the last decades by not only using subsurface seismic, borehole drillings, shallow geophysical methods or geomorphological observations but also by paleoseismological trenching. By studying prehistoric earthquakes, the location, recurrence and magnitude of future earthquakes can be estimated. The Vienna Basin is characterized by moderate historical and instrumental seismicity. Quaternary basin subsidence and active faulting in the Austrian part of the Vienna Basin is indicated by geomorphological features like fault scarps and the offset of Quaternary terraces of the Danube. Studies show, that faults in the Vienna Basin can produce earthquakes with a maximum magnitude of Mmax = 6.0–6.8 and geological data suggest slip rates of 1–2 mm/yr for the main strike-slip fault system. Studies on normal faults that formed at releasing bends of the strike-slip system like the Aderklaa-Bockfließ Fault (ABF) and the Markgrafneusiedl Fault (MF) also show Quaternary activity with a maximum slip rate for the ABF of 0,05 mm/a for the last 200 kyr and for the MF 0,02 to 0,05 mm/a. With this study, we present data from a segment of the Seyring Fault, which is one of the normal faults compensating extension at releasing fault bends of the VBTF. The Seyring Fault System is an approximately SW-NE striking normal fault, delimiting the Gänserndorf Terrace in the west, from the terrace west of Seyring. The Pleistocene Gänserndorf Terrace in the central Vienna Basin, formed by the fluvial plain of the Danube, is dissected into several parts by the Aderklaa-Bockfließ Fault and the Markgrafneusiedl Fault. The terrace deposits represent glacial- and interglacial periods. Seismic profiles, electrical resistivity tomography (ERT) data and borehole data were used to locate a segment of the Seyring Fault 3.4 km NNE of the city limits of Vienna. From the borehole data, ERT and seismic profiles an offset in the Quaternary sediments of about 15 m could be observed. Further evidence for Quaternary deformation was derived from trenching of the Seyring Fault segment. Here, several normal faults at a depth of approximately 2 meters below the surface could be observed terminating at three event horizons and off-setting a succession of gravel, sand and loess. A clear Quaternary offset, the maximum slip rate and the magnitude of the earthquakes could be derived from the observations in the trench. Furthermore, the deformation history for six events and a time stratigraphic framework could be constructed with ^{14}C ages derived from gastropod samples. These six events observed in the trench took place in a time period between 31.96 kyr and 14.99 kyr BP producing several displacements of the sand and loess layers and three colluvial wedges with a maximum offset by a single event of about 0.4 m which is indicative of an earthquake with a magnitude of M = 6.4. The smaller colluvial wedges and offsets are estimated to be produced by earthquakes with magnitudes between M = 4 and M = 5.5.

Deformation of a mountain-sized olistolith: Schwarzer Berg, Northern Calcareous Alps of Salzburg

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Passive and active continental margins are sites of emplacement of huge slides and olistoliths. In most cases, some kind of tectonic process leads to mobilization of large blocks of the sedimentary succession. If these continental margins are involved in an orogeny at a later stage, it may be difficult to distinguish very large slides from nappes. We studied deformation at the base of the Schwarzer Berg olistolith that has a thickness of 1.5 km and several km length and width. It consists of Triassic limestones and dolomites, and a discontinuous carpet of evaporitic shales and cellular dolomites (Permian Haselgebirge) at the base. It was emplaced into Jurassic pelagic siliceous shales of the Lower Juvavic Lammer zone of the Northern Calcareous Alps south of Salzburg. Cross sections of the olistolith demonstrate that the basal carpet is flat, but an internal anticlinal structure exists within the olistolith on top. Both limbs are truncated at the level of the carpet. The basal contact of the olistolith to the Jurassic pelagic siliceous shales is characterized by the absence of major and pervasive macroscopic deformation features. It is an irregular, wavy surface. Right below the contact in the Jurassic siliceous shales cm-scale verging folds occur. In a calcareous layer 50 cm below the contact, bookshelf structures are found, in another layer 80 cm below the contact brecciated clasts occur. The kinematic indicators allow to deduce a transport direction towards the east. Locally, the lower viscous sediments are injected into the higher viscous dolomite of the olistholith. This interface resembles a mullion-type structure. The cusps are up to m-scale and filled with the Jurassic shales where the olistolith rests on the Jurassic strata. In addition, there are also cusps at contacts to Permian Haselgebirge shales in several m-scale that follow pre-existing striated faults within the dolomite. On the microscopic scale, cataclastic deformation is observed in the Triassic dolomites at the base of the olistolith, and in the uppermost calcareous layer of the Jurassic, but not in the Jurassic deposits below. There, deformation features are almost absent corresponding to the field observation. The structural inventory can be related to three different stages of structural evolution: The km-scale antiformal structure resembles the geometry of a turtle anticline that might have developed during (1) breakaway of the olistolith. The absence of pervasive deformation at the base of such a large olistolith points to (2) transport of the olistolith on a layer of overpressured fluid, or a Haselgebirge salt pillow. In the first case, fluid pressure must have been high enough to support the olistolith. The existence of asymmetric mullion-like structures documents simple shear and traction at the base of the olistolith. This requires fluid pressure release and (3) grounding of the olistolith, associated with formation of mullions, folds and bookshelf structures. Final emplacement of the olistolith on Jurassic sediments requires a topography at the sea floor, which could have been formed by late Jurassic thrusting that has been observed at Trattberg N of Schwarzer Berg.

Minibasins upside down – Salt tectonics in the Karwendel mountains, Northern Calcareous Alps of western Austria

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The western Northern Calcareous Alps (NCA) are outside of the classical salt occurrences of the Eastern Alps. However, the salt mine of Hall in Tirol and numerous exposures of Haselgebirge, the solution residue of originally salt-bearing shales, give evidence of the presence of salt. This part of the NCA has a sedimentary succession starting with Permian (Haselgebirge) to Lower Triassic evaporites, overlain by carbonate platforms reaching a total thickness of more than 2 km. Two structural domains can be distinguished. A southern domain is characterized by a fold train of symmetric, WSW-trending folds with a wavelength of 6–8 km. In a northern domain, a km-scale recumbent fold is observed. The inverted limb has a length of at least 7 km. Within this inverted limb we observe minibasins that have their base in the summit region of the mountains. Due to high topography (up to 2 km), the entire minibasin fill is exposed in mountain walls. The basins are filled by lagoonal platform carbonates, sunken into Permo-Triassic evaporites. In the southern domain, the abovementioned fold train is characterized by parallel bedding (except forereef clinoforms). New field work in the area revealed major normal faults within the platform, with up to 1 km offset displaying Triassic growth strata in their hanging wall. The abundance of recumbent slump folds, locally sheath folds, and seismites (clastic dykes and sills, ball-and-pillow structures and breccia layers) in the platform carbonates is conspicuous. The thickness of the Ladinian to Carnian part of the platform (Wetterstein limestone) varies between 1.5 and almost 4 km. All this may relate to the presence of salt and salt-bearing shales at the base of the sedimentary succession, causing tilting of blocks and associated seismic activity. Thrust geometries in the northern domain only make sense when more than a km of salt is imagined that disappeared subsequently. Currently, the thrusts are bent around minibasins, however, during activity these must have been straight. Nappe transport and emplacement onto Lower Cretaceous deposits was probably only possible after salt evacuation and weld formation. During inversion of the passive margin in the Cretaceous, the NCA rocks were detached along the evaporite decollement and stacked onto Cretaceous synorogenic sediments. Initial lower Cretaceous transport of the thrust sheets did not create folds. Erosion during late Cretaceous shortening created the evaporite-cored detachment folds of the fold train and the recumbent fold.

A high-resolution seismic survey across the Balmuccia Peridotite, Ivrea Zone, Italy – Project DIVE

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The Ivrea Verbano Zone (IVZ) is one of the most complete crust–upper mantle geological references in the world, and the Drilling the Ivrea-Verbano zone project (DIVE) aims to resolve the uncertainties below this area. Geophysical anomalies detected across the IVZ indicate that dense, mantle-like rocks are located at depths as shallow as ca. 1–3 km. Thus, within DIVE several geological, geochemical and geophysical studies are planned, including the drilling of a 4 km deep borehole that will penetrate the Balmuccia Peridotite (Val Sesia, Italy), a peridotite body that outcrops in the IVZ. The objective of this borehole is to approach, and possibly cross, the crust–mantle transition zone, and provide for the first time geophysical in-situ measurements of the deepest rocks of the IVZ. One of the primary requirements before drilling is a seismic site characterization, to define with precision the correct positioning and orientation of the borehole, to assess potential drilling hazards and to allow for the spatial extrapolation of the borehole logs. For that goal, two joint geophysical surveys were performed in October 2020 in a collaboration between GFZ Potsdam, Université de Lausanne and Montanuniversität Leoben: (1) a deep seismic survey performed by GFZ Potsdam, entitled SEismic imaging of the Ivrea ZonE (SEIZE), consisting of two approximately orthogonal 15 km-long seismic lines, that aim to resolve the deeper structure of the IVZ in the area, and (2) a smaller seismic survey at the proposed drill site, entitled Highresolution SEismic imaging of the Ivrea ZonE (HiSEIZE), geared towards providing high-resolution seismic images of the uppermost few km. In this study, we focus on the HiSEIZE data. The area of study is characterized by high-velocity crystalline rocks, which imposes several challenges for reflection seismology: Lithologic impedance contrasts in crystalline crust are usually weaker, the spatial coherence of reflections from faults and fractures is quite limited, steep dips are predominant, and the strong contrast between the weathering layer and the crystalline basement impedes the penetration of the wavefield generated by the source. These problems must be addressed by applying processing approaches that differ from classical imaging of sedimentary structures. This project will not only provide site characterization for the DIVE project, but also contribute to understanding the structure of the Balmuccia Peridotite, its changes in depth and its relationship with the crustal-mantle transition.

News from the International Commission on Stratigraphy

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The International Commission on Stratigraphy (ICS) is the largest and oldest scientific body in the International Union of Geological Sciences (IUGS). Its primary objective is to define precisely global units (systems, series and stages) of the International Chronostratigraphic Chart that, in turn, are the basis for the units (periods, epochs and age) of the International Geological Time Scale; thus, setting global standards for the fundamental scale for expressing the history of the Earth. Besides other activities, ICS and IUGS ratifies the Global Stratotype Sections and Points (GSSPs) and produced and updates the International Chronostratigraphic Chart (ICC) (https://stratigraphy.org/ICSchart/ChronostratChart2022-02.pdf). The Austrian Commission on Stratigraphy (ACS) is the national suborganisation to ICS and part of the Austrian National Committee for Geosciences (ONKG) the national representation to IUGS. While the ICC represents the official version of chronostratigraphic/geochronologic units and terminology in English language, the Austrian and German Commission on Stratigraphy translated the ICC in German (https://stratigraphy.org/ICSchart/ChronostratChart2022-02German.pdf) which represents the official units and terminology in German language. After ratification of the hierarchical level subseries/subepoch for the Quaternary (Lower/Early, Middle, Upper/Late Pleistocene; Lower/Early, Middle, Upper/Late Holocene) the International Subcommission on Stratigraphic Classification (ISSC) submitted a proposal that subseries/subepoch should become generally a formal tier in chronostratigraphic/geochronologic hierarchy. This proposal was ratified by IUGS and subseries/subepoch is now a formal hierarchical level between stage/age and series/epoch and was also included in the online version of the International Stratigraphic Guide (https://stratigraphy.org/guide/). If useful, each subcommission can include this rank into their respective interval of the stratigraphic column. After the Quaternary also, the Neogene adopted this tire including Lower/Early, Middle, Upper/Late Miocene; Lower/Early, Upper/Late Pliocene) in the ICC. As a consequence, the positional identifiers have to be written in upper case initials for the Neogene and Quaternary what is important for editors of scientific journals. The ISSC continued in preparing a series of articles dedicated to the various stratigraphic subdisciplines with the basic chapter on lithostratigraphy taking advantage of newly developed techniques to measure and evaluate rock properties and other attributes. This paper was published in Newsletters on Stratigraphy and deals not only with lithostratigraphy s. str. but describes and discusses also the closely related subdisciplines lithodemic stratigraphy and allostratigraphy supported by a selection of case studies.

Cenozoic lithostratigraphic units of Austria (sedimentary successions)

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The Stratigraphic Chart of Austria 2004 (ASC 2004) has been prepared and published without explanations of the depicted lithostratigraphic units. The original plan was to publish a description of all units shown on the ASC 2004 during the following years. So far, only the lithostratigraphic units of the Paleozoic have been published. Concerning the two other era(them)s – the Mesozoic and Cenozoic – it turned out that after so many years after publication of the ASC 2004 the lithostratigraphic units have considerably changed in number, definition and status compared to the chart. This encouraged a work group of the Austrian Commission on Stratigraphy to compile the lithostratigraphic units of the Cenozoic. The idea of this compilation was not to revise or formalize units but just describe the status quo representing a catalogue of so far described Cenozoic lithostratigraphic units in Austria. The descriptions of the lithostratigraphic units are presented in English and follow a fixed scheme. Only the name of the respective unit is documented first in German followed by the English expression. This was chosen because nearly all units treated here where originally named in German language and are also included in the geological maps in German language. The number and sequence of each description follows the recommendations of Steininger & Piller (1999) and matches those of the published Paleozoic volume (Hubmann et al., 2013). This list for each unit includes the following characteristics: Validity, Type area, Type section, Reference section(s), Derivation of name, Synonyms, Lithology, Fossils, Origin, Facies, Chronostratigraphic age, Biostratigraphy, Thickness, Lithostratigraphically higher rank unit, Lithostratigraphic subdivision, Underlying units, Overlying units, Lateral units, Geographic distribution, Remarks and Complementary references. Remarks may also directly follow the description of each category where necessary. For the locations of Type area, Type section and Reference section(s) international geographical coordinates (latitude, longitude) are provided. The lithostratigraphic units are arranged according to the major tectonic units including Cenozoic sediments and sedimentary rocks in a geographic arrangement from west to east and in stratigraphic order from older to younger. The tectonic units relevant for the Austrian Cenozoic are the Austroalpine Unit, Helvetic Unit, Ultrahelvetic Unit, Rhenodanubian Flysch Unit, North Alpine Foreland Basin, Waschberg Unit, Vienna (and Korneuburg) Basin, Eisenstadt-Sopron Basin, Oberpullendorf Basin, Styrian Basin, Fohnsdorf Basin and Lavanttal Basin. The definition of the tectonic units follows roughly the usual schemes which are applied for the official geological maps of Austria. Quaternary sediments deviate from the geographical-stratigraphic scheme and are summarized in a single unit. They are, so far possible, stratigraphically arranged from older to younger. Most Quaternary units do not meet formal lithostratigraphic requirements but represent a mixture of glacial phenomena linked to their stratigraphic position. Only a few exceptions match formal lithostratigraphic rules. Altogether 342 lithostratigraphic units have been described including 267 Formations or formation level units, 54 Members, 1 Subgroup, 13 Groups and 1 Supergroup.

The natural occurrence of native iron in basalt from Bühl near Weimar, Kassel, Germany: a new study based on historical samples

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The occurrence of metallic iron within the Miocene basaltic intrusion in Bühl is historically known and was investigated in detail around 1920. However, most of the publications are only in German, remaining unavailable nowadays for the broad scientific community. Bühl presents some features that are different from those shown by other well-known occurrences of native iron in basalt, namely Ovifak-Disko Island (Greenland) and in the Putorana plateau (Russia). These notable characteristics include: the lack of Ni, the occurrence of iron in nodules, each with different properties and not equally spread across the basalt, the presence of magnetite in the basalt (indicating partial oxidation of Fe), the occurrence of pyrrhotite and troilite in association with the metallic iron, and, finally, chemical and isotopic differences. The formation of native iron in the case of Bühl has been explained by local reduction of the basalt, induced by interaction with coal seams and local organic-rich sediments. The influence of reducing CO volcanic gases was excluded in the historical literature. The iron occurrence in Bühl has been completely exploited and, nowadays, the only accessible samples are in museums and private collections. The Natural History Museum Vienna owns a series of historical hand specimens and petrographic thin sections from this locality. Here, the first results of a study of this historical material, using newly prepared polished sections, is presented. Up-to-date analytical methods for petrography and geochemistry, and a modern petrologic approach will be used to investigate the close relationship between the metal and the basaltic fractions. A comparison with the results of the historical studies will be also provided. This work aims to improve our understanding of the formation process of native iron in the basalt from Bühl, and to provide additional constraints to the current formation model proposed for any natural occurrences of metallic iron in basaltic rocks, based on the reduction of basalt by crosscutting carbon or organic-rich layers.

Praxisorientierte Untersuchung und Klassifizierung anisotroper Festigkeitseigenschaften von Festgesteinen

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Der Begriff der „Anisotropie“ beschreibt in der Ingenieurgeologie und Felsmechanik richtungsabhängige geomechanische Eigenschaften - ein Verhalten das für viele Sediment- und metamorphe Gesteine, die eingeregelte Schichtsilikate enthalten, typisch ist. Für praktische Anwendungen im Tief-, Tunnel- und Spezialtiefbau stellt die Erkennung und Beschreibung anisotroper Eigenschaften von Festgesteinen daher insbesondere im Kontext der Festigkeitsbewertung eine herausfordernde Aufgabe dar. Eine Vernachlässigung anisotroper Effekte bei der Untersuchung birgt das Risiko irreführender (üblicherweise zu niedrig ermittelter) Gesteinsfestigkeitswerte, die folgenreiche Konsequenzen, nicht zuletzt hinsichtlich der Leistungsbeurteilung bei der Gebirgslösung, nach sich ziehen können. Der vorliegende Beitrag stellt den aktuellen Kenntnisstand zur Festigkeitsuntersuchung anisotroper Gesteine vor. Für Zwecke der Klassifizierung des spezifischen Grads anisotroper Festigkeitseigenschaften wird der „Anisotropie-Index“ (AI) als praxistauglicher Index vorgeschlagen, sowie Empfehlungen zu Probenahme- und Untersuchungsstrategien aus praktischen Projektanwendungen vorgestellt.

Empfehlungen und Empfehlungsarbeit des AK 3.3 „Versuchstechnik Fels“ der Deutschen Gesellschaft für Geotechnik e.V.

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Der 1976 als „Arbeitskreis 19, Versuchstechnik Fels“ gegründete Arbeitskreis AK 3.3 der Deutschen Gesellschaft für Geotechnik e.V. erarbeitet Empfehlungen für felsmechanische Labor- und Feldversuche sowie Messungen im Gebirge und an geotechnischen Bauwerken. Mit den Empfehlungen werden Messprinzipien, die Anforderungen an Geräte sowie Vorgehensweisen für die Durchführung und Auswertung felsmechanischer Versuche und Messungen festgelegt. Damit soll erreicht werden, dass felsmechanische Versuchs- und Messergebnisse auch überregional miteinander vergleichbar sind. In den ersten 45 Jahren seiner Tätigkeit hat der Arbeitskreis insgesamt 25 Empfehlungen publiziert, die sowohl thematische Neubearbeitungen, als auch in den nationalen Kontext übertragene internationale Normen und Empfehlungen (wie z.B. die ISRM Suggested Methods) umfassen. Die Empfehlungen des AK 3.3 finden über die Grenzen Deutschlands hinaus Beachtung und Anwendung im deutschsprachigen Raum und viele der bisher veröffentlichten Empfehlungen sind im weiteren Normierungsprozess in DIN, EN und ISO-Normen überführt worden. Ein Kompendium aller 25 Empfehlungen wird im Herbst 2022 im Verlag Ernst & Sohn erscheinen. Der Beitrag gibt einen Überblick über die ersten 25 Empfehlungen des AK 3.3 und die aktuelle Empfehlungsarbeit des AK 3.3.

Tonrohstoffforschung an der Geologischen Bundesanstalt

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Tone und Lehme werden seit Jahrtausenden als Baurohstoffe sowie für keramische Erzeugnisse genutzt. Als äußerst vielseitige mineralische Rohstoffe eigenen sie sich jedoch auch für eine Vielzahl von speziellen Anwendungsmöglichkeiten. Die österreichischen Tonvorkommen weisen altersmäßig wie auch genetisch ein breites Spektrum auf, das sowohl fluviatile, limnische, brackische, marine als auch äolische Sedimente in allen Verwitterungsstadien umfasst. Die Erforschung und Dokumentation dieser Vorkommen wird im Rahmen der Baurohstoffforschung an der Fachabteilung Rohstoffgeologie der Geologischen Bundesanstalt betrieben. Sie beinhaltet neben der generellen Bestandsaufnahme und der laufenden Implementierung neuester Daten und Erkenntnisse in Archive und Datenbanken auch die Abwicklung von Projekten zu speziellen Aspekten in Zusammenhang mit Tonrohstoffen sowie Beiträge zu interdisziplinären Fragestellungen. Diese schließen beispielsweise substratspezifische und agrargeologische Untersuchungen zur Geologie als Standortfaktor für den Schutzwald oder für den Weinbau, die Dokumentation kurzfristig zugänglicher Aufschlüsse im Zuge von Großbaustellen oder die Bearbeitung geotechnischer oder geophysikalischer Fragestellungen mit ein. Zu den wichtigsten laufenden bzw. kürzlich abgeschlossenen Projekten, die vorgestellt werden, zählen „IRIS Baurohstoffe“, die im Rahmen der Forschungspartnerschaften Mineralrohstoffe durchgeführten Projekte „MRI_LössLehm“ und „MRI_SpekDroTon“ sowie das im Rahmen des Vollzuges des Lagerstättengesetzes durchgeführte Projekt „Karbonatarme Tonrohstoffe in Österreich“. „IRIS Baurohstoffe“ baut auf den Ergebnissen des Österreichischen Rohstoffplans auf. Rund 80 Tonrohstoffbezirke werden bearbeitet und in das Interaktive Rohstoffinformationssystem IRIS Online implementiert, sodass letztlich zu jedem einzelnen dieser Rohstoffbezirke per Mausklick Angaben zu stratigraphischer Einheit, Form, Alter, Besonderheiten, Verwendung, typischen Vorkommen sowie weiterführender Literatur abfragbar sein werden. Für das Projekt „MRI_Lösslehm“ wurden in einem interdisziplinären Ansatz an der Geologischen Bundesanstalt vorliegende Analysendaten zu Gesamtmineralogie, Tonmineralogie, Geochemie und Korngrößenverteilung unter rohstoffgeologischen Gesichtspunkten beurteilt und mittels statistischer Methoden ausgewertet und gruppiert. Ziel des Projektes „MRI_SpekDroTon“ ist die Detailuntersuchung ausgewählter Tonvorkommen Österreichs hinsichtlich ihrer rohstoffgeologischen Eigenschaften sowie ihre flächige und tiefenmäßige Verbreitung. Dabei sollen vor allem auch die Möglichkeiten bisher noch wenig etablierter Verfahren wie Punktspektrometrie und Drohnen-gestützte geophysikalische Messverfahren ausgelotet werden. Das Projekt „Karbonatarme Tonrohstoffe in Österreich“ soll einen bundesweiten Überblick über den aktuellen Forschungsstand erstellen sowie durch gezielte Probenahmen, geophysikalische Messkampagnen und Laboranalysen dazu beitragen, die Rohstoffqualitäten und -quantitäten dieser vor allem auch in Hinblick auf eine klimafreundlichere Ziegelproduktion relevanten Rohstoffgruppe besser einschätzen zu können.

Evidence for a two-stage brittle tectonic evolution from fault analyses in the Horn Basin (SE Bohemian Massif)

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We provide an overview of faults and nappe boundaries mapped during the ongoing geological mapping project on sheet Horn in the southeastern Bohemian Massif. The tectonic boundary between the Moldanubian and the Moravian Superunit, the Moldanubian Thrust, roughly defines the northern and eastern margin of the Horn Basin structure. At this tectonic contact, Moldanubian mica schist overlies the Moravian granodioritic Bíteš Gneiss. However, younger brittle deformation produced the area's recent geomorphology. The eastern marginal faults of the Horn Basin have been the focus of brittle tectonics assessment. Several fault segments and smaller-scale faults were mapped in detail to gain an insight into the tectonic evolution of the basin. Faulting activity of the approximately N-S trending structures on the eastern margin was initiated by left-lateral strike-slip displacement along the NE-SW trending Diendorf Fault System. This resulted in antithetic Riedel shears, probably close to the brittle-ductile transition, with dextral strike-slip activity and associated vertical displacement. Causing also steepening of mica schist and Bíteš Gneiss foliation, this deformation phase mainly formed the tectonic windows of Moravian Bíteš Gneiss in Moldanubian rocks. Reactivation of the N-S trending faults during at least one younger deformational phase afterwards shaped the recent geomorphology of the basin. A roughly E-W directed extensional regime was observed at the eastern margin in many outcrops by means of tension gashes, conjugate joint sets and normal faults. Furthermore, altitude correlation of Oligocene—Neogene sediments proposes post Egerian–Ottnangian normal faulting activity, mainly westwards, during this late extensional phase. The evolution of the E-W orientated northern margin of the Horn Basin is less well known; clearly, it shows intense brittle deformation close to the Moldanubian Thrust. Brittle normal faults are either running E-W or represent NW-SE to N-S trending conjugate fault sets. The NW-SE trending ones presumably are the result of displacement along original joints, since joints mostly trend NW-SE or NE-SW and synkinematic quartz recorded oblique-slip shear sense. The creeks and valleys often seem to follow the NW-SE orientated brittle structures. Additionally, steep dip of mica schist foliation may indicate strike-slip activity along the E-W trending northern margin of the basin. Remnants of Miocene sediments again suggest later southward subsidence in or after early Eggenburgian times and Pleistocene to Holocene debris flows from the northern as well as the eastern margin of the Horn Basin reflect landscape response to faulting and denudation of the fault scarp. The investigations reveal a two-stage brittle tectonic evolution of the marginal faults of the Horn Basin. An early-stage brittle-ductile strike-slip activity, probably late Carboniferous to early Permian in age, could be shown for the N-S trending faults, which is most likely triggered by the Diendorf Fault System. The late-stage subsidence and basin formation took place during at least one extensional phase with displacement from Egerian–Ottnangian onward. The data on fault geometry, kinematics and, as far as possible, timing of tectonic activity, were added to the fault database of the Geological Survey of Austria (GBA).

A thermometric database for the Eastern Alps based on Raman spectroscopy on carbonaceous material (2002–2022)

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Since 2002, Raman Spectroscopy on carbonaceous material (RSCM) was applied in carbonaceous material-bearing meta-sediments of the Eastern Alps to explore the tectono-metamorphic history of cover and basement rocks involved in the orogeny. After establishing a general correlation between spectral parameters and peak metamorphic temperatures by Beyssac et al. (2002), major methodological progress was achieved by the development of the “Interactive Fitting of Raman Spectra” (IFORS) approach of Lünsdorf et al. (2017), providing a standardized analytical protocol to estimate error validated metamorphic temperatures between 160 and 600 °C. This technique allows the effective thermometric mapping within major parts of the Eastern Alps. The implementation of this approach initiated the cooperation of the Leoben Raman-lab with the Geological Survey of Austria (GBA). During this work, stratigraphically, tectonically, and kinematically well-constrained samples were investigated. From the results, a map-based database was created, which allows plotting the data at geological maps in different scales. The presentation shows the current state of the map, including all RSCM data of the last two decades analyzed in the Leoben Raman-lab. The data allow a much better coverage of the pre-Alpine, Eoalpine and Alpine metamorphic zoning in the units of the Eastern Alps and support recent mapping projects of the GBA. Partly they are already published.

Formation and environmental significance of short-range order allophane hisingerite solid-solutions

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The chemical weathering of silicates and the subsequent formation of clay minerals are important processes within Earth's critical zone, affecting, for instance, the pH value, the water-bearing capacity, the ion exchange properties and the availability and mobility of nutrients in soils. Short-range ordered (SRO) minerals such as allophane ($\sim Al_2O_3 \cdot (SiO_2)_{1.3–2} \cdot (H_2O)_{2.5–3}$) and hisingerite ($\sim Fe^{3+}_2Si_2O_5(OH)_4 \cdot H_2O$) are common secondary weathering products in soils, but the relationships between the ambient environmental conditions, SRO-mineral formation paths and their resulting crystal-chemical properties are poorly understood. Therefore, end-members and solid-solutions of the allophane-hisingerite series were precipitated at different molar ratios of Al/Si, Fe/Si and (Al+Fe)/Si at ambient temperature using batch experiments in order to study the nature, chemical composition and nanostructure of the precipitates. The obtained SRO-minerals were characterized by XRD, FTIR, (E)SEM and TEM techniques. The reactive aqueous solutions were continuously sampled over a period of 2 weeks and analyzed using ICP-OES to investigate the temporal evolution of Al, Fe and Si during SRO-mineral precipitation. Preliminary results indicate that solid solutions with homogenous products were obtained and that allophane-hisingerite formation occurs within seconds to few minutes under the chosen experimental conditions. This might proceed via an instantaneous precipitation of Al/Fe-bearing octahedral template sheets onto which silicate tetrahedrons are getting attached through condensation and polymerization reactions. Silicon isotope analyses of the reactive fluids and solids will provide further insights into the specific physicochemical conditions and pathways of SRO-mineral formation at low temperature.

Forum Bergbau und Wasser – Hydrogeologische Begleitforschung zum Ende des Deutschen Steinkohlebergbaus – Hydrogeochemische Aspekte am Beispiel Anthrazitbergbau Ibbenbüren

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Nach dem Ende des industriellen Steinkohlenbergbaus in Deutschland mit dem Jahr 2018 bleiben in den betroffenen Regionen an Ruhr, Saar und Ibbenbüren umfassende Herausforderungen für nachfolgende Generationen. Zu diesen „Ewigkeitsaufgaben“ gehören auch und vor allem Fragen rund um das Grubenwasser. Im aktiven Bergbau wurde es an die Oberfläche gepumpt, um den Abbau zu ermöglichen. Mit dem Ende des Bergbaus werden Lösungen gesucht, um mit dem Grubenwasser umweltgerecht und gleichzeitig wirtschaftlich umzugehen. Ein nachhaltiges Grubenwassermanagement setzt ein hydrogeologisch/hydrochemisches Verständnis aller Prozesse im Grubengebäude aber auch in den jeweiligen Einzugsgebieten voraus. Das Forum Bergbau und Wasser wird von einer Gruppe HydrogeologInnen aus Deutschland, Österreich und Südafrika gebildet. Es war zwischen 2017 und 2022 damit befasst, wissenschaftliche Grundlagen für ein langfristiges Grubenwassermanagement zu schaffen. Die Arbeitsgruppe der Universität Salzburg hat sich dabei vor allem den hydrochemischen und isotopenhydrologischen Aspekten des Grubenwassers gewidmet. Die Identifikation der individuellen geochemischen Prozesse, die zur jeweiligen Wasserzusammensetzung führen, bildet die Basis für Prognosen über die langfristige Entwicklung des Grubenwassers nach Flutung und ist die Grundlage zur Festlegung eines optimalen und nachhaltigen Grubenwasseranstiegsniveaus. Dies wird im Vortrag am Beispiel des Anthrazitbergbaus Ibbenbüren dargestellt. Mit dem Ziel einer hydrogeochemischen Systemanalyse wurde eine Beprobung des Grubenwassers in verschiedenen Höhenniveaus und der umgebenden tiefen und seichten Grundwasservorkommen durchgeführt. In den dabei entnommenen Proben wurden die anorganischen Haupt- Neben- und Spurenkomponenten, radiogene ($^{87}Sr/^{86}Sr$, Tritium) und stabile Isotope ($^{34}S/^{32}S$, $^{18}O/^{16}O$, $^{2}H/H$, $^{13}C/^{12}C$) analysiert, um die Reaktionsmechanismen der Wasser-Gesteins-Interaktion zu identifizieren. Die Proben des tiefen Grundwassers sind durch hohe Gehalte an gelösten Ionen, vor allem Natrium und Chlorid charakterisiert. Über die Br/Cl Verhältnisse können diese Salzgehalte eindeutig der Steinsalzlösung zugeordnet werden. Die Analyse der stabilen Schwefel- und Sauerstoffisotopensignatur im Sulfat deutet für diese Wässer zusätzlich auf eine Herkunft aus den mesozoischen, das Bergwerk umgebenden, Sedimenten hin. Lithium und Kaliumgehalte, sowie die Signatur des $^{87}Sr/^{86}Sr$ Verhältnisses zeigen eine weitergehende Interaktion des tiefen Grundwassers mit den Sedimenten des Karbons. Im Vergleich dazu verringern sich die Salzgehalte in den Grubenwässern aus den höheren Bereichen des Bergwerks deutlich. Mit abnehmender Tiefe entwickelt sich die Isotopensignatur des gelösten Sulfats in eine für Sulfid-Oxidation typische Richtung und der Einfluss der mesozoischen Sedimente geht zurück. Die Ergebnisse der Fallstudie zeigen, dass ein kontrollierter Anstieg des Grubenwassers auf ein oberflächennahes Niveau zu einer Verringerung von Lösungsfrachten aus dem tieferen Aquifer führt. Ein auf Basis der Erkenntnisse optimiertes Grubenwasseranstiegsniveau führt mittel- bis langfristig zu einer erheblichen Energieeinsparung. Vor allem aber kommt es durch die Entlastung der Vorfluter zu einer Verbesserung der Gewässerqualität und zur Regeneration der umgebenden Aquifere, Entwicklungen, die deutlich im Sinne der Europäischen Wasserrahmenrichtlinie zu sehen sind.

Landscape rejuvenation in the Bohemian Massif

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The Bohemian Massif represents the relic of a major Paleozoic mountain range, which was eroded and levelled in the Permian but experienced relief rejuvenation during the last few million years. The landscape is characterized by rolling hills and extended planation surfaces above an elevation of about 500 m. However, at lower elevations deeply incised gorges confined by steep hillslopes are abundant and contrast impressively with the low relief landscapes above. Rivers with a bimodal morphology (i.e. steep at lower elevations and gentle at higher elevations) drain either to the north into the Vltava River or to the south into the Danube River. Hence, a continental drainage divide runs through the Bohemian Massif and changes in the course of the divide eventually control the Central European drainage pattern. In this study we aim quantifying spatial and temporal variations of landscape change in the Bohemian Massif. To characterize the two contrasting landscape states, we computed landscape metrics derived from digital elevation models (e.g. normalized steepness index, geophysical relief). To determine the rate landscape change we are currently computing catchment-wide erosion rates from the concentration of cosmogenic ^{10}Be in river sands. Results show that the landscape is characterized by out-of-equilibrium river profiles with migrating knickpoints currently at elevations between 450 and 550 m. Knickpoints are separating steep channel segments at lower elevations from less steep channels at higher elevations. Hypsometric maxima at or close above knickpoint elevations along with high and low values in geophysical relief downstream and upstream of major knickpoints support the idea of landscape bimodality with higher erosion rates in steep low-lying portions of the catchments. Furthermore, we found a strong drainage divide asymmetry, which evidences for the reorganization of the drainage network of the region. Across-divide gradients in channel steepness predict the northward migration of the Danube-Vltava drainage divide including growth and shrinkage of tributary catchments at the north and south of the drainage divide, respectively. For the first time we will present catchment-wide erosion rates from 20 catchments spread across the Bohemian Massif and discuss whether erosion rates are consistent with landscape metrics and related predictions.

Interaction of metamorphic and deformation processes in the Hohl eclogite body (Koralpe, Eastern Alps, Austria)

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In this contribution, we present petrographical, chemical and microstructural data from a series of eclogite samples derived from low Mg-high Ti gabbro collected at the Hohl eclogite body in the Koralpe Range (Eastern Alps, Austria). Our investigations suggest a strong interaction between chemical (i.e. metamorphism) and mechanical (i.e. deformation) processes operating at eclogite facies conditions. The rocks are characterized by a pronounced foliation defined by the shape preferred orientation of the major minerals (omphacite, amphibole, epidote and garnet). Minor euhedral quartz grains are present. Overall, grains show rather uniform extinction which is well in line with a low internal distortion detected by electron backscatter diffraction mapping. These features are interpreted as evidence of fluid-triggered syn-tectonic diffusion dominated eclogitization. Thermodynamic forward modelling indicates that eclogitization occurred under fluid saturated conditions at about 1.8 GPa and 640 °C. Continuous prograde metamorphism is resulting in dehydration of eclogite, consequently increasing the pore-fluid pressure and causing brittle failure of the eclogite. Fractures are subsequently sites of re-precipitation with a similar paragenesis as the host eclogite. However, the veins that formed by this process are enriched in quartz and epidote, depleted in garnet and show overall a coarser grain size. Deflection of the host-rock adjacent to veins indicates a ductile reactivation as flanking structures localizing the deformation. The reactivated veins are characterized by undulatory extinction, twinning and subgrain formation, all being indicative of dislocation creep. The investigated samples testify how metamorphic reactions dictate the style of deformation in the eclogite body. While fluid-supported eclogitization initially allows for the accommodation of ductile strain via diffusion-dominated processes, posteclogitization dehydration triggers brittle deformation. Finally, quartz and epidote enriched veins can deform by dislocation creep.

A fundamentals mineralogical investigation of downhole cements within the context of underground hydrogen storage

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Hydrogen is nowadays considered a promising way of storing energy from renewable energy sources, helping to overcome capricious weather as well as seasonal variations, hence increasing the efficiency of renewable energy sources. When it comes to storing energy, the calorific value per volume of the energy-storing medium is one of the most important key figures. Due to the low density of hydrogen, the calorific value per volume is significantly lower compared to other common energy fuels (e.g., natural gas). Therefore, vast storage volumes are needed. Underground Hydrogen Storage (UGHS, e.g., the idea of using natural geological reservoirs like depleted gas fields) promises great potential due to vast storage capacities. However, to make UGHS a feasible process, fundamentals research investigating not just the integrity of reservoir and cap rocks but also downhole materials used in boreholes against hydrogen is essential. Boreholes provide access to geological reservoirs but are also the bottleneck of any production or storage operation. In general, boreholes are lined with downhole materials, consisting of a steel casing surrounded by cement. The cement acts as a bonding between the steel casing and the wallrock, providing mechanical stability and tightness for the hole. However, the effect that hydrogen might have on the mineralogical phase composition and subsequently on physical and mechanical parameters of downhole cement is still very scarcely known. This project, which is part of a PhD programme of Montanuniversität Leoben on H_2 production and storage, aims to contribute to a better fundamental understanding of this issue. Basic mineralogical methods (XRD, FE-SEM, EPMA) were applied to determine the mineralogical phase composition of a downhole cement class G (according to American Petroleum Institute classification). Additionally, the influence of additives (silica fume and carbon black) on the phase composition and subsequently physical and mechanical parameters was investigated. Physical parameters such as porosity, pore size distribution and permeability were measured using Hg porosimetry, N_2 sorption and nitrogen permeation. The mechanical properties were characterized by determining compressive and tensile strength as well as applying hardness measurements of the individual phases using nanoindentation. Thermodynamic modelling using the software GEMS (Gibbs Energy Minimization Selector) indicates that certain phases within hardened cement pastes are susceptible to hydrogen alteration caused by the strong reducing character of hydrogen. Especially ferric iron and sulphate bearing phases like brownmillerite, AFm (Al, Fe monosulphate) and ettringite are altered, resulting in the formation of magnetite and iron sulphides. In a next step, autoclave experiments are planned to try validating hydrogen induced mineralogical reactions as indicated by thermodynamic modelling.

Tackling challenges concerning the integrity of downhole cement/rock during underground gas storage: an interdisciplinary approach

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As we are getting closer to the mid 2020-decade current energy politics aim for an environmentally sustainable and secure energy supply resulting in the substitution of conventional fossil fuels by renewable energy sources. This is accelerated by the necessity of reducing greenhouse gas emissions to combat climate change and reaching the net zero goals by 2050 as implemented by the European Commission. To overcome weather and seasonal fluctuations in the energy production from e.g., wind or solar sources and thus address a significant challenge to the broad implementation of a sustainable energy transition, the promotion of large-scale and secure energy carrying gases is a necessity. One promising way of storing nowadays important gases (e.g., H_2, CH_4, CO_2) is underground gas storage (UGS). UGS is the concept of using natural geological bodies in the underground as potential storage sites. Potential applications of UGS are power to gas (PTG), large scale safe hydrogen storage (UHGS) or carbon capture and storage (CCS). Geological bodies suitable for UGS are aquifers, salt caverns and depleted oil and gas fields with the latter ones making up the majority. Other advantages of depleted fields are that already existing infrastructure, e.g., boreholes and surface handling facilities, can be widely used, therefore preventing high initial investment costs. Moreover, the reservoirs are already fairly well understood. However, to make UGS a feasible process, fundamental research investigating not just the integrity of reservoir and cap rocks, but also downhole cements applied in boreholes during the storage life of the well are essential. This is particularly important once the injection scale is industrial, as there is a severe knowledge gap regarding the interaction of these fluids with the downhole cement, which is a significant element for the well integrity and therefore safety. This study is an interdisciplinary approach among geoscientists and drilling engineers at Montanuniversität Leoben trying to link potential gas induced changes in the mineralogical phase composition of reservoir rocks and downhole cements to changes in their physical and mechanical parameters. In various projects a collection of siliciclastic sedimentary rocks as well as downhole cements were investigated. Important investigated parameters were permeability and porosity as well as compressive and tensile strength. The mineralogical methods applied were XRD, EPMA, SEM and optical microscopy. Using mathematical models to correlate the density, p-wave velocity and compressive strength, ultrasonic measurements were conducted to provide insight regarding the potential damage to the samples. The rationale of the investigations is to compare non-treated samples (baseline) with those exposed to well-defined gas compositions for longer time spans. The experiments were done using hydrothermal autoclaves (100 bar, ambient temperature) and individual experimental runs lasted 3 to 4 weeks.

P-T-t Evolution of the Pongyang Gneiss, Inthanon Zone, NW-Thailand

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The Pongyang gneiss occupies a dominant portion within the Doi Suthep Complex, part of the Inthanon Zone, NW-Thailand, which is usually overlain by Paleozoic sedimentary rocks. Within the area, abundant granitoid rocks occur, which belong to the Central Granitoid Province in Thailand. Here, we present petrography, mineral chemistry, geothermobarometric and geochronologic results for the Pongyang gneiss. The Pongyang gneissic rocks comprise various light-colored to dark grey varieties depending on the amount of biotite. The typical mineral assemblage comprises garnet, quartz, plagioclase, K-feldspar (perthite), biotite, sillimanite (inclusions in garnet) and sometimes muscovite with accessory minerals ilmenite, pyrite, apatite, monazite, xenotime, and zircon. Plagioclase, quartz, biotite, and muscovite coronas developed around partly resorbed garnet porphyroblasts, which is indicative of a pressure decompression history. Garnet also contains numerous mineral inclusions such as sillimanite, quartz, biotite, muscovite, monazite, etc. Garnet composition is mostly almandine-rich and is slightly zoned with enrichment of spessartine content at the resorbed rim. Plagioclase in the matrix is sometimes zoned with an albite-rich rim and elevated anorthite contents within the core. On the other hand, the plagioclase corona composition is more anorthite-rich than plagioclase in the matrix. P-T conditions were calculated by the Garnet-Biotite-Plagioclase-Quartz (GBPQ), and Garnet-Biotite (GB) geothermobarometers to 6.0–7.0 kbar and 680–750 °C. The growth of plagioclase, quartz, biotite, and muscovite coronas around garnet occurred during exhumation at slightly lower conditions of 4.0–6.0 kbar and 640–660 °C. Monazite grains are observed as small (5–10 µm), anhedral to subhedral inclusions in garnet. The monazite grains discovered in the matrix (10–25 µm) are larger compared to the inclusions in the garnet and have usually fringed rims. The Th-U-total Pb dating of monazite (inclusions and matrix grains) yielded 192.08 ± 3.60 Ma in sample Sm-62-4 and 189.08 ± 5.41 Ma in sample Sm-62-5. The Pongyang gneiss of the Doi Suthep complex experienced upper amphibolite to lower granulite facies metamorphism at pressures of around 6 kbar in the Early Jurassic with a subsequent retrograde decompressional history. The metamorphic event is related to the late-stage collision between the Sibumasu block and the Sukhothai terrane.

The usage of GIS edge-approximation tools on vintage aerogeophysical data with focus on fault interpretation

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The reuse of vintage datasets can pose challenges for modern geophysical modelling, due to missing detailed preprocessing information or significant uncertainties or lack of precise tracking, etc. Nevertheless, they are often the only available datasets in a target region. We explore here the potential of such vintage airborne geophysical datasets (magnetic, AEM, radiometric) to detect the location and dip direction of geological faults, using a non-modelling interpretation approach based on multiple edge-approximation GIS tools. The study area comprises the eastern Bohemian Massif between the Moldanubian Shearzone and the Diendorf-Boskovice Fault System and the Northeastern Molasse Basin south of the Austrian-Czech border, including various fault types in different geological settings. The study area is covered by several aerogeophysical datasets obtained in the 1980s and 1990s and commonly reprocessed in 1998 are available. The applicability of the tools used in this study depend on the geological setting of each fault and is evaluated based on the comparison with geological data. In general, edge-approximation tools, especially used on a combination of datasets, show reliable results concerning the location and strike of faults, and even seem to be able to predict reliably the dip direction of a fault.

Die „Geräusche der Erde“ rund um und im Traunsee – Projekt TiefenRausch

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Die ZAMG wurde eingeladen für das Projekt „Tiefenrausch“ des Kurier Medienhauses die Geräusche der Erde im und rund um den Traunsee aufzunehmen und hörbar zu machen. Der Traunsee ist mit seinen 191 m der tiefste See in Österreich. Den Abschluss des Projektes ist ein bemannter Tauchgang mittels U-Boots bis zur tiefsten Stelle. Um die Geräusche der Erde rund um den See bzw. auch im See aufzunehmen werden am Gipfel des Traunsteins, am Seeufer und Unterwasser Seismometer installiert. Die Unterwasserstation befindet sich in rund 25 m Tiefe. Die Messstationen zeichnen die Schwingungen der Erde auf. Zusätzlich wird ein Hydrophon im Bereich der tiefsten Stelle installiert und die Signale, die ins Wasser übertragen bzw. im Wasser entstehen werden kontinuierlich aufgezeichnet. Die Datenauswertung geschieht auf Hinblick der natürlichen lokalen und menschlichen Einflüsse im und rund um den See. Hierbei spielen sicher die Bewegungen auf dem Wasser, der Tages-Wochengang des menschlichen Noise eine Rolle. Steinschlagereignisse, das Schwingen des Traunsteins im Wind und Beben dienen als natürliche Quelle von Geräuschen. Um diese Geräusche hörbar zu machen, werden die aufgezeichneten Daten mit ca. 15-facher Geschwindigkeit abgespielt.

Materialbestimmung von Gebäudeteilen mittels Ground Penetrating Radar

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Der Bausektor ist der größte Verbraucher von Rohmaterialien. Ein Wandel von einer linearen Wirtschaft in eine Kreislaufwirtschaft ist dringend notwendig. Urban Mining ist eine Strategie zur Rohstoffgewinnung aus bestehenden Gebäuden, wodurch der Wandel in eine Kreislaufwirtschaft ermöglicht werden kann. Dabei werden Gebäudebestände als wichtige Quelle materieller Ressourcen identifiziert. Jedoch fehlt das Wissen über die genaue materielle Zusammensetzung, um die zukünftige Nutzung modellieren und prognostizieren zu können. Die Bestimmung der Materialien erfolgt traditionell durch invasive Methoden, wie z.B. Bohrungen, wodurch die Qualität von potenziell wiederverwendbaren Elementen und rezyklierbaren Materialien beeinträchtigt sind. In diesem Paper präsentieren wir den Einsatz von Ground Penetrating Radar (GPR) um Hochwurten. Im Rahmen von zwei Forschungsprojekten wurden Wände und Böden in über 10 Gebäuden vor dem Abriss mittels einer 1,6 GHz bzw. einer 1 GHz Georadar Antenne linienhaft gemessen. Diese Messlinien wurden jeweils einem Element im dazugehörigen BIM-Modell zugeordnet. Zur Verifizierung der Daten wurden die Ergebnisse aus Bohrungen verwendet. Die Geometrie der Wände und Böden kann durch GPR sehr genau bestimmt werden. In den Radargrammen zeigen sich der Schichtaufbau und Dicke der Wände und Böden, wobei auch Leitungen, Hohlräume und Bewehrungen eindeutig zu erkennen sind. Klar kann auch zwischen Fußböden und Decken unterschieden werden. Eingebaute Stahlbetonträger sowie Dippelbäume zeichnen sich sehr gut ab. Zur Bestimmung der Materialien von den Wänden wurde versucht eine automatische Klassifikation durchgeführt zuführen. Dabei wurden in einem ersten Versuch die Energie (E) und Frequenz (F) der ankommenden Radarwellen der 1., 2. und 3. Maxima (jeweils ein positiver und negativer Wellenzug) bestimmt. In der Gegenüberstellung von E zu F konnten mehrere Klassen definiert werden. Ein Hohlbeton kann hier gut gegen Vollbeton unterschieden werden. Weitere Klassen zeigen vor allem die Unterschiede von markanten Bestandteilen wie Styropor, Bitumen, oder Mineralwolle. Zur Unterscheidung der Böden wurde in einem ersten Ansatz die Mächtigkeit des Betons und die Art der Bewehrung herangezogen. Die Fußböden und Deckenaufbauten sind sehr inhomogen und vielschichtig. Eine automatische Klassifizierung der Fußböden und Decken ist daher schwierig. Die Auswertungen zeigen aber das Potential der Materialbestimmung von Gebäudeteilen mittels Ground Penetrating Radar. Um diese zu automatisieren wurde auch versucht die Klassifizierung mittels eines Machine Learning Algorithmus durchzuführen.

Early results from the ICDP project DOVE (Drilling Overdeepened Alpine Valleys): Revisiting the Hole of Bad Aussee

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The sedimentary infill of glacially overdeepened valleys provides an excellent archive of the timing and extent of past glaciations. The first phase of the pan-alpine project DOVE (Drilling Overdeepened Alpine Valleys), co-funded by the International Continental Scientific Drilling Program (ICDP), investigates several drill cores from overdeepenings along the northern side of the Alps and their foreland. One of the investigated sites (ICDP-5068-5) is located near Bad Aussee (Austria), in the central part of the Northern Calcareous Alps within the extent of the former Traun Glacier. After geophysical investigations had pointed to the existence of a large salt body, an exploratory drilling recovered 880 m of Quaternary sediments. The succession mostly consists of fine-grained sediments covered by coarse gravels and basal till from the Last Glacial Maximum (LGM). The drill core was first described by van Husen & Mayr (2007), who proposed the formation of a more than 900 m deep lake following the dissolution of a salt body by subglacial meltwater. However, questions regarding the mechanisms and timing of the formation of this so-called “Hole of Bad Aussee” remain since comparable sites are unknown in the literature. As a part of DOVE Phase-1, the drill core is reinvestigated in detail to improve our knowledge of the Quaternary glaciation history of the Eastern Alps. So far, a sedimentological core description was completed and samples for grain size and total organic and inorganic carbon analysis were taken. The potential for numerical age dating using luminescence and terrestrial cosmogenic nuclide approaches is currently being explored to help establish a chronology of the pre-LGM development of the basin. In this presentation, we present results from the sedimentological core description, field mapping and DEM analysis, which provide new insights into the internal structure and depositional history of the Bad Aussee Basin.

Forschungsprojekt GeoDrone: Geotechnische und petrophysikalische Aspekte

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Beim vorliegenden Projekt GeoDrone handelt es sich um ein gemeinsames, von der Österreichischen Forschungsförderungsgesellschaft (FFG) gefördertes, Forschungsprojekt zwischen dem Lehrstuhl für Subsurface Engineering der Montanuniversität Leoben und der Firma Geosaic GmbH. Ziel des Projektes ist die Auswahl und Anwendung von Artificial Intelligence (AI) Algorithmen bzw. die Neuentwicklung von AI Architekturen zur Lösung von geologischen Fragestellungen von klassischen Fotos und 3D Drohnenaufnahmen. Das Projekt gliedert sich in zwei große Bereiche: den geotechnischen bzw. petrophysikalischen Aspekten sowie dem AI Workflow. Diese Präsentation befasst sich vorwiegend mit den Inhalten des ersten Blocks. Der dafür gewählte Aufschluss befindet sich hinter dem Lüftergebäude, beim Westportal der beiden Straßentunnel, des Tunnelforschungszentrums „Zentrum am Berg“ (ZaB) in Eisenerz. Um geotechnische Parameter der vorliegenden Geologie zukünftig den Drohnenfotos zuweisen zu können, sind dem Aufschluss Gesteinsproben entnommen worden. Die zugehörigen Gesteinsparameter wurden im Labor durch verschiedenste geotechnische und petrophysikalische Tests ermittelt. Parallel dazu erfolgten die Planung und Befliegung mit zwei unterschiedlichen Drohnen. Zusätzlich wurden vor jeder Befliegung Marker-Punkte entlang und auf dem Aufschluss vermessen, um eine koordinative Zuordnung jedes Bildpunktes zu ermöglichen. Anhand dieser berührungsfreien Messmethode konnten unter Anwendung der Photogrammetrie (Software: Agisoft und CloudCompare), 3D Punktwolken erstellt werden. Die Befliegungen und Auswertungen haben gezeigt, dass der Winkel der Kamera der Drohne bzw. wie die Planung der Flüge durchgeführt wurde (senkrecht oder waagrecht), einen großen Einfluss auf die Ergebnisse der Photogrammetrie haben. Eine vertikale Einstellung der Kamera in Verbindung mit 30 Grad von der horizontalen, mit vertikal platzierten Marker-Punkten und sehr naher Befliegung lieferten die besten Ergebnisse. Bei den vorliegenden Proben handelt es sich um verschiedene Varietäten des Sauberger Kalks sowie Ankerit und Siderit. An diesen Proben wurde im Labor die einaxiale Druckfestigkeit (UCS) bestimmt, Ultraschallmessungen (Vp und Vs) durchgeführt, sowie die Gesamtdichte, Korndichte und effektive Porosität ermittelt. Die geotechnischen und petrophysikalischen Aspekte des Forschungsprojektes GeoDrone konnten somit vorwiegend abgeschlossen werden und verschiedene Extraktionen von Daten aus dem Datensatz für den AI Workflow werden bereits durchgeführt.

A Miocene polarity transition recorded in a volcanic section on St. Helena, South Atlantic

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St. Helena is a small remote island in the South Atlantic at 16° S and 5.7° W. Although located in the so-called South Atlantic Anomaly of the Earth's magnetic field, the first paleomagnetic study of secular variation was performed only recently. Engbers et al. (PNAS, 117: 18258, 2020) discovered a profile of six lava flows ranging from Prosperous Bay Plain to Fisher's Valley, which recorded a reversed-to-normal polarity transition with three intermediate directions. These lavas were following a massive landslip and filled the associated cuvette rapidly with approximately horizontal lava flows. The profile was resampled and extended by four lava flows in our study. Furthermore, another parallel profile following Fisher's Valley to the sea was sampled consisting of twelve lava flows. Five to ten oriented paleomagnetic cores were taken per flow. Mean characteristic remanent magnetization (ChRM) directions have been obtained by alternating field (AF) and thermal demagnetizations. In some cases, the AF demagnetization suffered from creation of large gyroremanences while during thermal demagnetization chemical alteration was observed. Great circle behaviour was observed in a few cases. Despite the small specimen numbers per flow the mean ChRM directions are reasonably defined for 16 of the sites having Fisher precision parameter k above 50 and α95 confidence radii below 13.3°. The ChRM directions of the previous study were reproduced and integrated. Profile 1 (10 flows) starts with 4 reversed polarity flows, followed by 3 transitional directions with virtual geomagnetic pole (VGP) latitudes between 32° and -15° and it ends with 3 normally magnetized lavas. Profile 2 also starts with reverse polarity lava, followed by a normal polarity flow. Above these, 6 reverse polarity lavas are found. Then 2 flows with low VGP latitude of around 18° have nearly the same directions as found in Profile 1. At the top of the profile, a normal polarity flow is present. The upper 9 flows of Profile 1 show very similar directions compared to the 5 uppermost flows of Profile 2. Accordingly, the transitional nature of the lavas is well supported by two independent sampling campaigns and two parallel profiles, while the lower part of Profile 2 shows only secular variation. New $^{39}Ar/^{40}Ar$ ages are available for 2 flows of Profile 1 (Engbers et al., JGR 127: e2021JB023358, 2022) giving an age frame of 8.0 ± 0.25 Ma for the upper parts of the profiles. They allow for correlation with the geomagnetic polarity time scale and the transition from C4r.1r to C4n.2n. Further $^{39}Ar/^{40}Ar$ ages are under work and will permit correlation of the lower part of Profile 2. Thermomagnetic curves of susceptibility and hysteresis measurements suggest titanomagnetites of single or pseudo single domain grain size with high and low Ti-content as carriers of the remanence. Many curves show strong irreversibility suggesting the presence of primary low-temperature oxidation or maghemitization. Paleointensity determination with the Coe version of Thellier experiments were hampered by the presence of secondary magnetization components and thermal instability of the magnetic carriers. They were successful for only for 12 out of 20 flows. The obtained paleointensity values are much lower than the present-day field strength and provide further evidence for a long-lasting low field in the South Atlantic Anomaly.

Intermediate field directions recorded in Pliocene basalts in Styria (Austria): Evidence for cryptochron C2r.2r-1

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Pliocene volcanic rocks from southeastern Austria were paleomagnetically investigated. For the study of paleodirection and paleointensity samples were taken from 28 sites which are distributed over 8 volcanoes (localities). Directional results from six sites have already been published by Pohl & Soffel (1982: Geologisches Jahrbuch, vol. 52, p. 137), they were resampled at the same place or nearby and their results were confirmed. Rock magnetic investigations revealed that magnetic carriers are Ti-rich or Ti-poor titanomagnetites with mainly pseudo-single domain grain size. Characteristic remanent magnetization directions were obtained from alternating field as well as from thermal demagnetization. Four localities give reversed directions agreeing with the expected direction from secular variation. Another four localities of the Klöch-Königsberg volcanic complex and the Neuhaus volcano have reversed directions with shallow inclinations and declinations of about 240° while the locality Steinberg yields a positive inclination of about 30° and 200° declination. These aberrant directions cannot be explained by local or regional tectonic movements. All virtual geomagnetic pole (VGP) positions are located on the southern hemisphere. Four VGPs lie close to the geographic pole, while all others are concentrated in a narrow longitude sector offshore South America (310° to 355°) with VGP latitudes ranging from -15° to -70°. The hypothesis that a transitional geomagnetic field configuration was recorded during the short volcanic activity at these five localities is supported by 9 paleointensity results and ^{39}Ar-^{40}Ar-dating. Paleointensities were obtained with the Thellier double heating method from nine sites. While mean paleointensity values of 56.6, 29.9 and 23.4 µT are associated with VGP latitudes above 70°, sites with intermediate poles give considerably lower values. The weighted mean obtained from four sites of the Klöch-Königsberg complex is 8.62 ± 0.06 µT, while the mean paleointensity from Steinberg is only 2.93 ± 0.07 µT. Corresponding virtual geomagnetic dipole moments range from 1.1 to $2.9 \cdot 10^{22}$ Am^2 for sites with low VGP latitudes below about 60° and from 3.0 to $9.3 \cdot 10^{22}$ Am^2 for sites with higher virtual geomagnetic pole latitudes. K-Ar data obtained from associated tuffs give an age frame from about 2 to 4 Ma. Two new ^{39}Ar-^{40}Ar ages were acquired for Klöch and Steinberg volcanoes for four and six specimens, respectively. These new ^{39}Ar-^{40}Ar ages of 2.51 ± 0.27 Ma for Klöch and 2.39 ± 0.03 Ma for Steinberg allow the correlation of the Styrian transitional directions with cryptochron C2r.2r-1 of the geomagnetic polarity time scale (e.g. Singer, B., 2014: Quat. Geochronol., vol. 21, p. 29). A cryptochron is a short geomagnetic event in which the geomagnetic field flips to opposite polarity with a duration of less than 10 to 30 kyr. Accordingly, at least 3 of the 4 investigated Styrian volcanoes may have been formed in a short time interval corresponding to the duration of a geomagnetic cryptochron.

Geophysical prospection of the ancient gold mining region “Karth” in Lower Austria

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The “Karth” is a wooded plateau southeast of the town of Neunkirchen in southern Lower Austria. The traces of Roman gold mining, which are still clearly visible in the terrain today, are large reservoirs and water pipe canals, over which water was led over a distance of up to 25 km into the mining area. The aim of the FWF project (P 30790-G25, 2018-2022) is the interdisciplinary investigation of this only Roman gold mining area known in the Eastern Alps. The combined interpretation of geophysical and archaeological information enables detailed exploration, far beyond the area of the excavation areas. Analyses of magnetic anomalies and electrical resistivity tomography prove to be particularly suitable. Geophysical prospection was not only used to plan the archaeological investigations, but also to understand the sites where it is not possible to dig. The geological unit mined by the Romans is the Loipersbach Formation (Loipersbacher Rotlehmserie). It is a secondary deposit in which gold in the form of small flitters occurs irregularly distributed. The Loipersbach Formation consists of reddish-brown to greenish clay and quartzitic gravel. The deposit is located on a basal complex of mica slate, Semmering quartzite and carbonate rock. The structure of selected reservoirs was investigated geophysically. High-resolution electrical tomography profiles were measured with a multi-electrode system for 100 steel electrodes (Earth resistivity meter 4point light 10W from LGM – Erich Lippmann – Geophysical Instruments, Germany). The comparison of repeat measurements and the generally small measurement errors shows that the data quality is excellent despite high contact resistances in the dry forest soil (2 to 5 kOhm). The inversion of the measured data was carried out with the software RES2DINVx64 (GEOTOMO SOFTWARE SDN BHD, Malaysia). The inversion models show strong structuring in all profiles with model resistivities from 50 to 1,200 Ohm.m. The heterogeneous structure of the ramparts is clearly expressed and the separation of the basin floors to the geological subsoil is clearly visible. A formation with resistance values of up to 400 Ohm.m corresponds to the geological subsoil (Loipersbacher Rotlehmserie). Magnetic measurements aimed at detection of building relicts and were carried out manually (due to the rough topography and dense forest) with GEM Systems proton magnetometers with 2 sensors at heights of 0.5 m and 2.0 m above the ground. The data quality is consistently excellent. The standard reductions (diurnal variation and IGRF were calculated in Excel and the anomaly grids were created in SURFER. Most of the values of the reduced magnetic anomaly in the prospecting areas are almost normally distributed with a mean value of +9 nT, which can be considered as a local field fraction. Specific outliers were due to interfering bodies near surface (not detected in the field), which could be proven by a significant correlation between magnetic anomaly and vertical gradient. The distribution of anomaly values shows an obvious correlation with the topography in the measuring field. Several interesting magnetic structures could be detected in different parts of the study area. However, none of the structures is regarded as evidence for an archeological site.

Geophysical prospection of the Pliocene volcanic massif Königsberg-Klöch in Southeast Styria (Austria)

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Results from geomagnetic and geoelectric measurements in the Pliocene volcanic massif Königsberg-Klöch are presented, which were acquired since 2008 in the frame of geophysical boot camps with more than 50 students as well as 3 Bachelor-theses and 1 Master-thesis. The available data comprise more than 12 k ground magnetic observations and 4 electrical resistivity tomography profiles up to 1,240 m in length in and all around the active basalt quarry. Accompanying oriented sampling provided representative material for laboratory determinations of the relevant petrophysical parameters. Total magnetic intensity measurements with GEM Systems proton-precession and Overhauser magnetometers yielded anomalies between -935 nT and +886 nT in 2 m sensor height after reductions, while the vertical gradient of the total magnetic intensity was comparably low in accordance with a significant depth extend of the anomaly sources. Noticeably, the natural remanent magnetization (NRM) of the basalts deflected strongly from the present-day Earth´s magnetic field, implying the need for a careful consideration of the NRM in the magnetic modelling. Electrical tomography was measured with AGI Sting instruments in Wenner and dipoledipole mode with up to 126 electrodes. The resulting models could be compared with borehole, seismic and outcrop data. Conveniently, due to the ongoing mining activities some geophysical profile positions of earlier investigation years coincided with rock faces in the quarry observed in later years. The southern part of the area around the hill Seindl is dominated by well layered scoriaceous tuff breccia with small lava flows covering massive intrusive nepheline-basanites which also form small vents and dykes from south to north. From the north of the quarry to the south-east (castle of Klöch) and in the areas near Zaraberg and Jörgen, big vertical columns (1 m diameter) indicate the formation of lava-lakes. Three volcanic centres are recognized in the southern area and one at the Königsberg in the north. The entire volcanic massive is underlain by ash-lapilli-tuffs with phreatomagmatic origin. The depression in the centre on top of the volcanic massif is covered by lake sediments with peperites at the base, layers of ash-tuff with accretionary lapilli and bomb-sags of volcanic bombs. Shallow extensive basaltic layers between Königsberg and Seindl can be explained as lava flows. Geoelectrical and geomagnetic measurements provided good means to detect the basalt bodies. Problems only occurred with small-scaled structures and bodies located close to each other.

Geoelectric monitoring of irrigation experiments at the Rautenweg landfill (Vienna)

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In the period from 06.07.2020 to 16.09.2020, a geoelectrical monitoring along 6 profiles with a length of up to 204 meters was carried out in the Rautenweg landfill to investigate the changes in the water content in areas with household waste during the implementation of irrigation. The conditions for monitoring the relative increase in water saturation during irrigation are favorable if the irrigation water has a significant contrast in terms of electrical conductivity to the landfill contents. Monitoring comprised 7 phases of investigation: (1) Construction of profiles, geoelectric “zero” measurements (state before irrigation), temperature measurements in gas wells and inclinometers with infrared thermometry and testing the suitability of the landfill water from an extraction well, which yielded an extremely high conductivity of 0.55 S/m at a temperature of 22 °C. (2) to (6) irrigation experiments employing different gas wells and irrigation lances with accompanying geoelectric monitoring along one profile during the irrigation (e.g. 1, 3, 5 and 19 hours after the start) and measurement of all 6 profiles after the end of irrigation. (7) Final ERT-measurements and temperature determinations in gas wells 1 month after the last irrigation experiment. All electrical resistivity tomography measurements were carried out with a LGM 4point light 10W Earth resistivity meter with up to 69 steel electrodes and a constant electrode spacing of 3 meters. At profile positions, where the deposited waste material formed a concrete surface, pre-drilling of mounting holes for the electrodes was required. Where necessary, the electrical ground contacts were improved by means of watering the electrodes before and throughout the measurements. The time needed for a complete ERT measurement was 60 to 90 minutes, depending on the array type and profile length. Measurement errors were consistently very small, and the best results were achieved with the Wenner array. Time-lapse inversion of the measured data was carried out with RES2DINVx64 (Geotomo Software SDN BHD, Malaysia) and the inversion models were exported to Surfer (Golden Software LLC, Colorado) for advanced grid operations and plotting. The top layer and large parts of the landfill body has a very low electrical conductivity and the contrast to the conductivity of the irrigation water is sufficiently large. The household waste in the investigated area yields strongly anisotropic water flow paths. Horizontal and vertical barriers within the waste volume limit the spread of the water introduced. Iron pipes of the gas wells act as electrical conductors, and they are displayed in the profiles as conductive structures. However, in geoelectric monitoring, the changes in electrical conductivity caused by irrigation are evaluated. In the immediate vicinity of the wells, these changes are not completely masked, but are less significant than at a sufficient distance (a few meters) from the gas wells. There was no loss of water due to discharge into the landfill subsoil. The final measurement 4 weeks after the end of the irrigation shows no or only minor changes in the conductivity distribution. The geoelectric method is generally very well suited for monitoring the water saturation in the Rautenweg landfill.

99 % der Erde sind heißer als 1.000 °C – Nutzen wir diese Energie

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99 % der Erde ist heißer als 1.000 °C, nur 0,1 % ist kälter als 100 °C. Wie können wir diese Energie nutzen? Der Wärmesektor ist in Österreich für etwa die Hälfte des Energieverbrauchs verantwortlich. Im weltweiten Durchschnitt nimmt die Temperatur um ca. 3 °C pro 100 m in die Tiefe zu. Drei Säulen prägen grundlegend die Forschung und Nutzung der geothermischen Energie. Als erste Säule muss die Technologie für die Nutzung der Wärme erforscht werden. Hier gibt es mehrere Aufgaben zu lösen. Aus welcher Tiefenlage kann mit welcher Methode die Wärme gehoben werden? Wir unterscheiden zwischen oberflächennaher und tiefer Geothermie. Bei der Oberflächengeothermie werden Tiefen von wenigen hundert Metern genutzt. Hier ist es notwendig, dass die Temperatur zusätzlich mit elektrischen Wärmepumpen für eine Nutzung gehoben wird. Bei der Tiefengeothermie ist die hydrothermale Nutzung an erster Stelle. Das bedeutet, dass heißes Wasser aus größeren Tiefen von mehreren tausend Metern entnommen, genutzt und wieder in das Gestein eingespeist wird. Die Voraussetzung für eine hydrothermale Geothermienutzung ist jedoch, dass im tiefen Untergrund ein Grundwasserleiter (Thermalwasserleiter) vorhanden ist. Eine andere Methode wäre, dass direkt kaltes Wasser in ein poröses Gestein eingespeist, im Untergrund erwärmt und dann entnommen wird. Die Porosität des Gesteins kann technisch hergestellt und verbessert werden und man spricht von „enhanced geothermal systems“ EGS. Die zweite Säule betrifft die geologischen Gunstgebiete in denen von Natur aus bereits poröse Grundwasserleiter im tiefen Untergrund vorhanden sind. Meist handelt es sich um Kalke, Dolomite oder Sandsteine. Diese Gesteine kommen typischerweise in Österreich in unseren Beckenlandschaften wie der Molassezone, dem Wiener Becken und auch dem Steirischen Becken vor. Hier ist es notwendig, die Strukturen des tiefen Untergrunds in 2.000–5.000 m mittels geophysikalischer Methoden zu untersuchen und zu beschreiben. Mit den Untersuchungsergebnissen können sodann Geothermie-Bohrungen geplant und durchgeführt werden. In der Steiermark haben wir bereits einige Vorzeigeprojekte im Großraum Fürstenfeld. Der Gemüseproduzent Frutura nutzt Wärmeenergie aus rund 3.000 m mit einer Temperatur von 130 °C. In der geowissenschaftlichen Forschung wird aktuell intensiv nach solchen geothermischen Gunstgebieten gesucht um den Wärmeschatz zu heben. Die dritte Säule zielt auf die Abnehmer der Wärmeenergie hin. Einerseits sind es Industriestandorte wie Frutura mit der Gemüseproduktion und andererseits sind es die Heizungen in unseren Gebäuden. Damit ist es sinnvoll, dass wir geothermische Energie in der Nähe von Ballungsräumen, am besten mit bereits vorhanden Nah- und Fernwärmenetzen finden. Eine interdisziplinäre geowissenschaftliche Forschung kann hier einen wesentlichen Beitrag für die Dekabonisierung der Wärmeversorgung in Österreich beitragen. Da die Wärmeenergie rund die Hälfte der Gesamtenergienutzung ausmacht, ist die Energiewende hochgradig von der Wärmewende abhängig. Nutzen wir diese Chance auch für Österreich!

Tiefe Geothermie Wien

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GeoTief EXPLORE läutet eine neue Ära der systematischen Erschließung der Geothermie in Österreich ein. Ergänzend zu den meisten, bislang in Europa durchgeführten, Erkundungsprojekten zur Nutzung der Tiefen Geothermie adaptiert das Projekt etabliertes Wissen der Kohlenwasserstoffexploration und führt dieses zu einer integrativen und interdisziplinären Studie zur Nutzbarmachung dieser erneuerbaren Energieform zusammen. GeoTief EXPLORE erkundet dazu das Potenzial im Osten Wiens, dem wohl produktivsten Geothermie-Reservoir Österreichs, bewertet es hinsichtlich geologischer, technischer und ökonomischer Risiken und leitet daraus einen Umsetzungsplan für die Erschließung umweltfreundlicher Wärme ab. Die seismische Erkundung wurde in mehreren Phasen durchgeführt. In einer frühen Projektphase wurden bestehende Seismikprofile der Erdölindustrie neu ausgewertet. Darauffolgend wurden hochauflösende 2D Seismikprofile neu aufgenommen und dienten als Planungsgrundlage für die Aufnahme der 3D Seismik Donaustadt. Diese 3D Seismikdaten wurden im Zuge des Forschungsprojekts bearbeitet und dienten als Basis für die Erstellung von geologischen Modellen für verschiedene Geothermiereservoire. Unter der Bearbeitung der seismischen 3D Daten werden Bearbeitungsschritte in der Zeitdomäne (sowohl Prestack als auch Poststack) mit üblichen Processingschritten verstanden. Im gegenständlichen Projekt mit Zieltiefen von bis zu 5.500 m können die sehr steilstehenden geologischen Strukturen des Geothermiereservoirs in der Zeitdomäne nicht ausreichend lagegenau abgebildet werden. Deshalb sind spezielle Tiefenmigrationen (PreStackDepthMigration) mit überdurchschnittlich großen Offsets – split spread zweimal 6 km – in Streichrichtung der geologischen Strukturen und nicht direkt über dem Zielgebiet liegend notwendig. Die 3D Seismikdaten wurden entsprechend dieser Voraussetzungen aufgenommen. Die geologische Interpretation der seismischen 3D Daten – sowohl in der Zeitdomäne als auch in der Tiefendomäne – stellte eine große Herausforderung für dieses Projekt dar und ist auch die Basis für viele nachstehende Arbeitsschritte, wie beispielsweise die strukturelle Modellierung, die hydraulisch-thermische Szenariensimulationen sowie die Abschätzung der assoziierten Seismizität. In der Interpretation der neu aufgenommenen 3D Daten wurden bestehende Daten aus Vorprojekten sowie der Kohlenwasserstoffindustrie berücksichtigt. Einerseits wurden die bestehenden Modellvorstellungen des kalkalpinen Baus des Untergrunds des Wiener Beckens überarbeitet. Andererseits wurden die unterschiedlichen Reservoirbereiche wie die Asperner Schuppe, die Esslinger Deckscholle sowie ein seichteres Ziel – das Aderklaa Konglomerat – erkannt, ausgewiesen und voneinander abgetrennt. Wesentlich waren die Bestimmung der genauen Positionen (x und y) sowie die Tiefenlagen (z) inklusive der Mächtigkeiten der einzelnen Reservoirbereiche.

Aquifer Thermal Energy Storage Vienna

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Das Projekt Aquifer Thermal Energy Storage Vienna (ATES Vienna) adressiert erstmals die Integration von Aquiferwärmespeichern in Fernwärmenetze mit dem Ziel der Konzeptionierung der ersten technischen Pilotanlage in Österreich. Zudem erfolgen die Identifikation bzw. Charakterisierung der vorhandenen ATES Ressourcen, deren wirtschaftliche Bewertung sowie die Erarbeitung optimaler regulatorischer Rahmenbedingungen. Im Detail werden folgende Hauptthemen behandelt werden: Analyse von saisonalen ATES (Kapazität > 10 GWh, Temperaturbereich > 40 °C) aus geologischer, technischer und wirtschaftlicher Sicht einschließlich der Bewertung von Integrationsoptionen in Fernwärmenetze (mit Fokus Wien und Österreich). Erstellung eines detaillierten Konzepts einer zukünftigen ATES Pilotanlage in Wien auf Basis der Nutzung bestehender Kohlewasserstoff-Bohrungen und/ oder auf Grundlage von neu zu errichtenden Bohrungen. Bewertung von sozioökonomischen und regulatorischen Rahmenbedingungen für ATES in Wien und Bewertung des Beitrages dieser Technologie zur Erreichung der österreichischen Klimaziele. Das Projekt erkundet erstmals das Potenzial der Nutzbarmachung von ATES für Fernwärmenetzanwendungen in Österreich und Mitteleuropa. Anhand der Ergebnisse des Projekts können wesentlichen Weichen für eine zukünftige Wärmeversorgung von Ballungsräumen auf Basis alternativer Energiequellen in Österreich gelegt werden.

Aktueller Wissenstand zum Aufbau des Weststeirischen Beckens

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In den letzten Jahren wurden im Zuge des EU-Projekts Ri(ver)-Charge sowie in ergänzenden nationalen Projekten reflexionsseismische Untersuchungen in den Weststeirischen Teilbecken von Eibiswald, St. Florian und Lieboch durchgeführt. Die neu gewonnenen Erkenntnisse ergaben eine Änderung der bisher angenommenen Beckengeometrie sowohl in Bezug auf die Tiefe als auch die Form. Des Weiteren konnte ein erster konzeptioneller Ansatz des geologischen Aufbaus erarbeitet werden, wobei für die Korrelation der geophysikalischen Schichtpakete zu den geologischen Einheiten noch keine Tiefenbohrung vorliegt. Aufgrund der Ergebnisse und der geologischen Rahmenbedingungen ist das Weststeirische Becken aus wasserwirtschaftlicher Sicht gut geeignet für die Erschließung potentieller Wasserressourcen in Beckenlagen. Zudem eignet sich das Weststeirische Becken bestens für Untersuchungen, um ein Prozessverständnis der Grundwasserneubildung von Tiefengrundwässern in Beckenlandschaften erarbeiten zu können. Aus den gewonnenen Erkenntnissen ist abzuleiten, dass eine Tiefenbohrung zur Kalbration der Ergebnisse unbedingt anzustreben ist.

Vom Altbergbau zur Altlast, Blei- Zinkvererzung Schrems bei Frohnleiten

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Die bergbaulichen Tätigkeiten im Raum Schrems lassen sich bis ins 13. Jahrhundert zurückverfolgen. Zur Blei- und Silbergewinnung wurden die lokalen Blei-Zinkvorkommen des Grazer Paläozoikums abgebaut; vornehmlich an Schwarzschiefer gebundener silberführender Bleiglanz, Zinkblende und andere komplexere Kiesvererzungen. Ab Mitte des 18. Jahrhunderts konzentrierte sich die Abbautätigkeit vor allem auf die unmittelbar oberhalb des heutigen Ortszentrums von Schrems gelegene südliche Talflanke des Talbachs. Dort befand sich bis 1874 mit dem Josefibau auch die bedeutendste Abbaustätte. Im Zuge von Untersuchungen gem. §13 ALAG wurden Untergrund- und Grundwasseruntersuchungen durchgeführt. Die Untersuchungen ergaben sehr hohe Bodenbelastungen durch Blei und Zink, sowie untergeordnet durch Cadmium und Quecksilber. Hohe Bleigehalte konnten auch in Gemüseproben nachgewiesen werden, die aus belasteten Hausgärten stammten. Eine Expositionsabschätzung und Risikoanalyse ergab eine mögliche gesundheitlich relevante Schadstoffaufnahme durch spielende Kleinkinder auf bleibelastenden Flächen sowie durch den Verzehr von Gemüse aus bleibelasteten Beeten. Beide Risiken waren als nicht tolerierbar zu beurteilen und die betroffenen Flächen wurden daher als Altlast ausgewiesen. Als Sanierungsmaßnahme wird derzeit in den Hausgärten der betroffenen Liegenschaften der Oberboden entfernt und durch nicht kontaminiertes Material ersetzt.

Prospecting for spodumene pegmatites by statistical evaluation of trace elements in magmatic muscovite

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During the past years, about 1,400 sites of pegmatite occurrences belonging to the Austroalpine Unit Pegmatite Province were investigated in the frame of the projects MRI_Pegmatite I/II. These projects are part of “Initiative GBA-Forschungspartnerschaften Mineralrohstoffe – MRI” and aim to investigate the economic potential of the rocks with respect to lithium and other rare elements. The investigated pegmatite dikes formed during Permian lithospheric extension by anatectic melting of aluminum rich metapelites. Based on the appearance in the field and the mineralogical composition simple pegmatite, evolved pegmatite, leucogranite and spodumene-pegmatite are distinguished. They appear in different levels of the Permian middle and lower crust embedded in certain host rocks. Field and analytical data concerning the investigated pegmatite occurrences are available in a database. Of special interest for prospection on additional spodumene-pegmatite dikes are more than 2,000 major and trace element contents on magmatic muscovite determined by SEM/EDX and LA-ICPMS. This collection of data allows the pegmatite occurrences to be categorized and visualized in maps showing regional fractionation trends and prospective areas in a variety of ways. Data analysis shows that commonly applied simple parameters such as K/Rb ratio are not able to distinguish the classes general pegmatite, leucogranite and spodumene-pegmatite because they are not distinct enough. In contrast, Classification and Regression Trees (CART) provide much more accurate predictions. The CART algorithm was used because, on the one hand, it creates binary decision trees that, in contrast to black box models such as artificial neural networks, can also be understood by non-experts and, on the other hand, this algorithm can deal with partially incomplete data sets. Before the calculation of the CART all muscovite analyzes were checked for correctness using statistical methods like box-plots and correlation matrices and then further examined using machine learning methods. The tree generated using all available data has a prediction accuracy of 97 %. This in-sample forecast overestimates the accuracy of the forecast. Dividing the available data into a randomly created training data set and a validation data set results in different trees depending on the data sets in the training data set. However, it allows carrying out out-of-sample tests. These still show a forecast accuracy of mostly over 94 %. It turns out that the lithium and beryllium contents are particularly well suited to distinguishing the different pegmatite classes. In addition to these, the elements cobalt, phosphorus, iron, zinc, lead, tantalum, titanium and manganese proved to be indicative. Based on the results about a dozen of potential spodumene-pegmatite occurrences were identified, which will be checked in the field in the near future.

Tectonic history of Hoop Fault Complex – Implications on fault transmissibility, Barents Sea/Norway

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The Barents Sea consists of several tectonic elements, which were formed at different plate tectonic collisional and rifting stages. This work focuses on the Early Mesozoic to recent events of the central Barents Sea, the eastern edge of the Bjarmaland platform. We have analysed the clastic deposits of Mid-Triassic to Upper Jurassic to reconstruct the tectonic history of the Hoop Fault Complex, Barents Sea/Norway. The obtained results served as input for a fault seal analysis (FSA). Apatite fission track and (U-Th)/He thermochronology were used to determine the maximum burial depths and exhumation history. According to the combined evaluation of results from shale ductility analysis (BIB-SEM), fault kinematic analysis and structural modelling (section balancing based on a 125 km long 2D seismic section line) the following tectonic evolution can be drawn: deflation of late Palaeozoic salt deposits was initiated by the tectonic activity on the early structures of the Hoop Fault zone. The orthogonal faults of the Hoop Fault Complex developed at the early stage, during Late Triassic to Early Jurassic times at relatively shallow depth, below 1,000 m. Ongoing subsidence related to the extension caused by the opening of the Atlantic Ocean created accommodation space for Upper Jurassic to Cenozoic deposits with maximum burial depth of 2,000 m for the analysed Mid-Jurassic rocks. The exhumation of the Hoop Fault complex started around 10 Ma and remained constant until Quaternary times (140 m/Myr). The purpose of this study was to use the quantified results as input to model and determine the sealing capacities of faults compartmentalizing a hydrocarbon accumulation. The fault rock calibration workflow requests a depth at time of faulting and maximum burial depth in order to perform a shale to permeability transform. Well-constrained values are crucial to limit the range of uncertainty with respect to fault transmissibility. Our study shows the importance of thorough reconstruction of the tectonic history and the impact of the expected results.

Development of a demonstration project for the construction of a compressed air storage in existing disused mining galleries based on geonumerical modelling

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In times of energy transition compressed air energy storage (CAES) is expected to increasingly gain importance as industry moves to greener and more sustainable energy sources and storage capabilities. The requirement for large volumes and very stiff containment for CAES makes subsurface excavations an ideal option for storage. Excavating new subsurface excavations, however, is expensive and resource-intensive, thereby posing a challenge for the use of CAES. With this motivation, this project aims to answer the following research questions: Is it possible to store compressed air inside an already existing, but disused, mining gallery? What are the limiting constraints for this? The results of this study highlight the challenges as well as a methodology to assess the technical and economic feasibility of CAES in disused mining galleries. This study presents an approach to selecting and characterising a disused mining gallery for eventual CAES experimentation, in the underground mining facilities of the Erzberg at the Dreikönig level as a case study, in four phases: The first phase focuses on the challenges of finding a suitable underground location in disused mining facilities. The second phase entails fieldwork, including mapping and characterising the accessible rock mass, mapping the existing gallery support, sampling rock material for laboratory testing, and conducting rapid strength tests on the small samples collected from rock exposures. The third phase is the experimental part in the lab, which is split in the preparation of thin sections, as well as performing non-destructive experiments, e.g. ultrasonic and porosity measurements and destructive experiments, e.g. UCS/triaxial and point load tests. The final phase consists of numerical modelling of the reaction of the rock mass to cyclic loading cause by pressurised air storage and extraction. Once the numerical modelling is completed, the feasibility of the project can be evaluated, as well as the maximum compresses air pressure that can be introduced in these facilities. The key challenges we encountered at the Erzberg are: complex geometry of underground mines, poor condition of support in disused galleries, and lack of access to the rock mass in areas covered by lining. The complex geometry of drifts and stopes in underground mines significantly limits the number of galleries in which to conduct CAES experiments. Support for underground mining galleries is often either non-existent or well below the requirements for safe subsurface work. The often disturbed and altered rock masses encountered in mines provide challenges for rock mass characterisation, such as lack of competent rock for laboratory testing. The methodology we adopted was in response to these challenges and provides a framework for future investigation of disused mining galleries for CAES, as well as other engineering uses.

Time series and trend analysis of Austrian springs

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On average, nearly half of the Austrian drinking water supply is provided by spring water. The actual demand of spring water depends highly on the region and is up to 100 % in alpine areas of Austria. The quantity, duration and seasonal patterns of the recharge of spring waters is expected to be altered due to climate change effects, affecting the runoff dynamics and storage behaviour. Thus, an adequate characterization of spring runoff patterns is essential for taking decisions in the future water management. Therefore, long-term data of 96 springs, which belong to the monitoring network of the Hydrographic Service of Austria, were investigated applying time series and trend analysis methods. The data sets contained spring discharge, electric conductivity and water temperature until end of 2017 with a temporal resolution of down to 15 minutes. Trends of the data were analyzed and compared between ten and twenty-year periods indicating an impact of climate change on the spring parameters. Moreover, the runoff pattern of each spring was characterised by its seasonality (Pardé Coefficient) and response time (autocorrelation). Based on these discharge attributes, 5 clusters of spring types were identified. Statistical evaluation indicates that springs with distinct seasonality show shorter response times, whereas the discharge with long response times usually fluctuates slightly within a year. Additionally, the regional linkage of the spring groups was explored indicating no distinct correlation between runoff pattern and the geological setting of the aquifers. These results highlight the significance of accurate spring characterization with regard to changes of spring runoff dynamics and storage behaviour for coping with the future challenges of water resources management.

Nanoindentation mapping for determining representative mechanical parameters of clay matrix in mudstones: A new tool for top seal characterization

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Nanoindentation is ideal for measuring micro- to nano-scale mechanical properties and structural heterogeneities, and is therefore increasingly applied to fine-grained sedimentary rocks which may serve as top seals of geological reservoirs. Traditional mechanical testing poses a challenge for such rocks, as i) the preparation of a well-defined macroscopic specimen is often impossible and ii) the availability of core material from underground storage prospects is limited. Knowledge of the mechanical behaviour of mudstones seals is important to understand their fracture behaviour which may cause mechanical seal failure due to microfracturing as a response to various geological processes (e.g., buoyancy pressure from the reservoir). In this contribution, first results of high-speed nanoindentation mapping on the clay matrix of top seals from the Vienna Basin are presented. The nanoindentation grids were deployed on clay matrix areas, as matrix-related pores are of great importance for the evaluation of pore network connectivity and overall mechanical strength. The nanoindentation results were then post-processed with machine learning-based tools (e.g., k-means clustering) to remove noise resulting from sub-optimal surface quality or the testing of mixed phases. Feasibility experiments were carried out using a Hysitron TS 77 Select (Bruker) equipped with a Berkovich diamond tip on one sample with two map arrays (7 × 7 indents). To test the depth sensitivity, the indentation loads were increased continuously from 500 µN to 1,500 µN over a total of 49 indentations, corresponding to an increase in indentation depth from ~150 nm to 450 nm, respectively. Indents on the matrix area were selected based on broad ion beam-scanning electron microscopy (BIB-SEM) maps and further analysed in correlation with the load-displacement data to exclude undesired effects such as the pop-in effect by sudden displacement or no loading due to existing cracks. The initial results show that despite the highly heterogeneous phase distribution in mudstones, mechanical parameters obtained from their clay matrix are not sensitive to indentation depths, and hence representative values can be determined from minimum volumes with statistical significance. The resulting average reduced elastic modulus (Er) and hardness (H) values of the clay matrix range at 16.32 ± 7.25 GPa and 0.47 ± 0.35 GPa, respectively for the tested sample. The established workflow was then applied to a vertical top seal section cored in the Vienna Basin well Bo-209 (Bockfließ), and vertical property changes (elasto-plastic deformation behaviour, Er, H) were linked to other rock properties such as bulk mineralogy, bulk geochemical indicators for hydrocarbon leakage (e.g., Rock-Eval S1 and production index) as well as porosity, pore geometry, and grain size distributions calculated from BIBSEM maps. In conclusion, this contribution aims at introducing high-speed nanoindentation mapping as a feasible high throughput tool for the mechanical characterization of mudstones.

Who needs geoscientists? Career options in a time of energy transition

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Historically, many geoscientists have been employed in searching for and extracting resources, either hydrocarbons, minerals, or water. Concerns about the environmental sustainability of geological vocations appear to be reducing the number of students studying geoscience, at least in many developed western nations. What then are the options for those wishing to pursue a career in geology? The need for geoscientists is paramount in a time of energy transition, be that in traditional spheres of employment or in what may be termed “sustainable geoscience,” although these are not mutually exclusive. Growing global population and economic growth are likely to drive an ongoing rise in energy demand as the century progresses. Despite the growth in renewables, the energy mix for the next few decades is likely to continue to include a significant contribution from natural gas, oil, and, to a lesser extent, coal. The challenge is to be as efficient as possible in the exploration for these resources and to locate those with the lowest carbon footprint created by their exploitation (“green oil”). This means a focus on reservoir geology so that well placements and trajectories are optimized. These skills will also allow geoscientists to contribute to solutions that may help achieve carbon neutrality targets. Carbon capture and sequestration (CCS) is likely to grow in importance and requires geoscientists who can model subsurface repositories and the behaviour of fluids injected into those repositories. Other avenues exist in engineering geology in relation to the challenges of installing new wind farms and for the construction of measures to mitigate the impacts of climate change that are already inevitable. A growing number of geologists are engaged in investigating the potential of geothermal energy. The global improvement of living standards and society’s ongoing appetite for technology places a demand on the supply of raw materials (e.g., copper and rare earth elements) that could quickly outpace our known reserves. Geoscientists are needed to locate new deposits, including those in the oceans. As the global population continues to expand towards 11 billion people, water supply is likely to be one of the major challenges society faces as the century progresses. Hydrogeologists are needed to locate and manage aquifers as climate evolves and to protect them from pollutants. Academic geologists can provide support to all of these industrial activities, but there is also much fundamental research to be carried out. It is now over 50 years since the advent of the last major paradigm shift in geoscience – plate tectonics – another is surely overdue. We still have much to learn about processes operating in and on Earth today and in the past, and the evolution of life. Holistic Earth systems science approaches can be useful, for example, by using the past to model climate evolution. One exciting avenue is the impact of the digital revolution on geoscience. Data science is providing new scientific insights and is transforming all resource industries, contributing to efficiency and associated environmental benefits. The future geoscientist needs to be technology and data science literate, but with an underpinning of sound geoscience knowledge. We do not know where this exciting phase of technology and data science change will take geoscience, but it is clear that geoscientists will be needed to support society as it enters a period of unprecedented change.

Regional mudstone compaction trends in the Vienna Basin: Implications for potential geological storage leakage

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Lacking core material poses a major challenge for seal capacity estimation particularly in basins with limited geological information. In such cases the threshold breakthrough pressure, at which capillary displacement of hydrocarbons into the seal may occur, can be estimated by using established empirical normal compaction trends. However, such trends only deliver semi-quantitative results and need to be calibrated for a specific basin setting. Therefore, this work aimed at calibrating existing normal compaction trends and resulting seal capacity models for Miocene (Pannonian, Sarmatian, and Badenian) seal rocks of the well-explored Vienna Basin, finally linking the estimated seal capacity with actual geochemical evidence for hydrocarbon leakage through the respective mudstone interval. To do so, 41 core samples from the Vienna Basin, covering a broad depth interval from 720 m to 3,270 m, were investigated with X-ray diffraction, mercury intrusion capillary porosimetry (MICP), He-pycnometry, and Rock-Eval pyrolysis to capture the free hydrocarbon content of the samples. Decreasing porosity depth trends are visible throughout all stratigraphic intervals. Sarmatian and Badenian samples show well-defined depth trends, while a wider porosity scattering is observed for Pannonian samples. Bulk mineralogy has no clear influence on the porosity and pore throat depth trends. MICP porosity plotted against calculated maximum hydrocarbon column heights (HCH) revealed a comparable trend to modeled seal capacity curves. Most low-porosity samples from great burial depths range at estimated HCH > 3,000 m, where capillary seal failure seems unlikely. Rock-Eval parameters S1 and production index (PI = S1/(S1+S2)) indicate present free hydrocarbons in all investigated mudstone intervals. These free hydrocarbons are clearly a sign of oil staining, as all samples can be considered as organic lean and shallower samples as thermally immature. Both parameters correlate well with the estimated HCH particularly for the Badenian sub-set of samples. These trends indicate that hydrocarbons from underlying reservoirs may have been vertically migrating through these seal layers, possibly implying a higher-than-expected vertical fluid mobility also in the fine-grained and lowpermeable sections of the Miocene Vienna Basin infill. Overall, the petrophysical data acquired in this study show that established mudstone normal compaction trends are generally suitable to estimate seal capacity in the Vienna Basin. Free hydrocarbon indicators (Rock-Eval S1 and PI) show clear signs of oil staining correlating with the estimated seal capacity. This supports the general validity of seal quality estimations based on normal compaction trends. The suggested significant vertical mobility of fluids in mudstone intervals may represent an additional contribution to the primarily faultcontrolled secondary hydrocarbon migration in the Vienna Basin. Furthermore, it must be considered in the planning of underground gas storage activities.

U-Th-Pb geochronology and initial Pb composition of magmatic allanite by LA-MC-ICP-MS

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Allanite-group minerals are rare earth element-bearing epidotes that incorporate not only U and Th but also non-radiogenic Pb. Isotopic analyses can thus simultaneously reveal the magmatic or metamorphic crystallization age of allanite as well as the ambient Pb composition at the time of crystallization. Whereas the first aspect has been the main focus of several studies, the second one has received much less attention. We use a collection of Phanerozoic, allanite-bearing magmatic rock samples (volcanic, plutonic, pegmatite) to devise a strategy for accurate determination of both age and initial Pb composition in allanite. We show that allanite data acquired by laser ablation-multi collector-inductively coupled plasma-mass spectrometry can be corrected for mass bias and fractionation using zircon (for U/Pb and Th/Pb ratios) and glass (for Pb/Pb ratios) as reference material as long as allanite is not metamict. We highlight the need for initial ^{230}Th disequilibrium correction, as both the lower intercept age and the y-axis intercept Pb composition can be significantly affected. The accuracy of allanite U-Pb dates obtained by linear regression in a Tera-Wasserburg diagram is confirmed by the good agreement with published U-Pb zircon ages for the same localities. The accuracy of initial Pb compositions is validated by a fair agreement with Pb isotopic data measured on co-genetic feldspars from the same samples. The initial Pb composition of samples ranging from ca. 530 to 18 Ma reveals fluctuations in initial ^{207}Pb/^{206}Pb ratio, which points to different degrees of crustal (elevated μ = ^{238}U/^{204}Pb) contribution. These variations could be due to post-magmatic deformation, weathering or metamorphism, but we believe that they rather reflect differences in initial magma composition. We therefore emphasize the importance of constraining initial Pb compositions using magmatic allanite to discuss the source of igneous rocks.

Investigating pore coupling effects in near-surface environments using nuclear magnetic resonance

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Assessing and monitoring underground water resources is of increasing importance to ensure the continuous supply of fresh water for human activity and endangered ecosystems. These underground water resources include fully saturated aquifers and soil moisture and rock moisture. Nuclear magnetic resonance (NMR) is a non-invasive geophysical method with unique sensitivity to water. It is based on the magnetization and relaxation process of the spin magnetic moment of hydrogen atoms forming water molecules. NMR technique has been applied for hydrocarbon exploration and hydrogeologic investigation where it helps to characterize underground water distribution and water transport in different geologic materials. However, the interpretation of NMR data from samples with complex and heterogeneous geometries requires the consideration of pore coupling effects, which is often neglected in routine NMR data analysis. A pore-coupled system presents a significant magnetization exchange between macro and micropores within the measurement time, which makes the independent characterization of each pore environment difficult. Previous studies have explored different factors controlling pore coupling, such as network geometry and surface geochemistry, using a wide range of methodologies including laboratory experiments and numerical modelling strategies. In this presentation, we search to review, assess, and expand on previous findings on pore-coupling effects using NMR and aim to propose a unifying model to describe the pore coupling effect in unsaturated condition. We applied a random walk simulation on a simplified two-connected-pores system to evaluate and compare the main controlling factors identified in literature. In particular, we tested the influence of surface relaxivity on the pore coupling effect, as well as the influence of the degree of physical connectivity between the pores (understood as the pore-throat length) and of the effects of pore sizes (both absolute and in relation to each other). Developing a better understanding of pore coupling effects and its mechanisms is of great importance for the accurate estimation of hydrogeological parameters from NMR data. Improving the interpretation of NMR data in complex geometries prone to pore coupling and in unsaturated conditions is essential for this approach to reach its full potential.

Silicon isotope fractionation during the formation of amorphous (alumino)silicate phases

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Weathering of silicate minerals and the resulting formation of clay minerals are key processes at the Earth's surface, which regulate for instance the ocean pH, atmospheric carbon dioxide (CO_2) budget, soil development and associated nutrient transfer. One key element in the diverse weathering processes is silicon (Si), which enters the biogeochemical cycle as dissolved silicic acid ($Si(OH)_4$ or DSi). In the critical zone, however, Si is frequently precipitated as short range ordered hydroxyaluminosilicate (HAS) phases, such as imogolite or allophane. The precise formation paths and the environmental controls on HAS formation, as well as their impact on Si isotope fractionation are not yet well constrained, and needs further investigation. For this purpose, a series of laboratory experiments will be performed at different pH and temperature conditions in order to resolve the reaction kinetics and mechanisms and conditions underlying the formation of amorphous silica and HAS phases. Besides the traditional oxygen (O) and hydrogen (H) isotope analysis, Si isotope fractionation between reactive fluid and solid phases is studied at high temporal resolution using the three-isotope method, which is a unique proxy to trace the direction and the progress of low-temperature water mineral/rock interactions. Understanding the behaviour of Si isotope fractionation under these different environmental conditions will provide further insights to mechanisms of HAS formation.

Combining NAA and best relative fit factors for provenancing

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Neutron Activation Analysis (NAA) employs a nuclear process to determine the concentrations of chemical elements at the percent, parts-per-million and even parts-per-billion level. Combining multi-element analytical capacity with sensitivity, precision and ease of sample preparation, NAA has become a privileged tool in provenance studies of archaeological ceramics. The application of NAA produces data on the elemental concentrations of up to 30 chemical elements. This so-called chemical fingerprint can then be used to find samples of chemically similar composition, in the case of ceramics, resulting in groups that share a common clay paste, i.e. the recipe that was used to produce the ceramic under investigation. During this process of comparison, several multivariate statistical methods need to be employed, most prominently a best-relative fit factor that enables the removal of additional statistical spread that is produced by slightly different amounts of temper used. Using real-world data as well as simulated datasets, the applications, limits and potential extensions of this combined approach will be presented.

Updates from Lake Paleoseismology as contribution to improve seismic hazard assessment and awareness of secondary earthquake effects in Austria

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In intraplate tectonic regions, only limited knowledge exists on the occurrence of severe earthquakes, their maximum possible magnitude, potential source areas and secondary effects such as seismically-triggered rockslides. This is mainly due to long recurrence rates exceeding the time span of instrumental earthquake records and historical documentation. Yet, knowledge of the earthquake history provides an important foundation of seismic hazard assessment. Motivated by the mission to fill the gap in long-term records of severe earthquakes and their consequences in Austria, we have studied lakes in Carinthia and Tyrol with a “Lacustrine Paleoseismology” research approach: We combined geophysical, sedimentological, and geochemical techniques to unravel and precisely date high-resolution lacustrine sedimentary sequences comprising records of past seismic shaking as subaqueous landslides, turbidites and in-situ sediment deformation. Based on the sedimentary imprint of well-documented historically and instrumentally recorded earthquakes with intensities ranging from V to IX (EMS-98) we derived (i) seismic intensity thresholds for different lake basins and (ii) scaling relationships between measurable sedimentary parameters and seismic intensity. These natural ground motion indicators have then been applied to the prehistoric lacustrine sedimentary records of different lakes to establish a first calibrated and multi-scale paleoseismic dataset for Carinthia and Tyrol. In Carinthia, the sedimentary archive of Wörthersee spanning the last ~14,000 years recorded 44 earthquakes of intensity > V (ranging between V and IX), with three intervals of strongly enhanced seismicity. Recurrence statistics and calculating the exceedance probability in 50 years of a certain intensity reveals the following conclusions: (1) Poissonian earthquake recurrence, as used in the probabilistic seismic hazard assessment by ZAMG, is confirmed for the last 2,800 years; (2) the current seismic hazard curves of the study area agree with the lacustrine paleoseismic record; (3) intervals of enhanced earthquake frequency can occur and need to be considered in seismic hazard analysis; (4) compared to the whole record, the last ~800 years show a relatively high number of strong intensity events. In Tyrol, our results show that 25 severe earthquakes are recorded in the three studied lakes Plansee, Piburgersee, and Achensee over the last ~16,000 years, from which four left imprints in two or more lakes. Earthquake recurrence intervals range from ca. 1,000 to 2,000 years with a weakly periodic to aperiodic recurrence behaviour for the individual records. Plausible epicenters and magnitude estimates of paleoearthquakes, as derived by a reverse application of an empirical intensity prediction equation in a geospatial scenario analysis, coincide with the current enhanced seismicity regions. Here, MW 5.8-6.1 paleo-earthquakes might have occurred that were larger than the more recent historical earthquakes. The largest prehistoric earthquake might have reached up to Mw 6.3 at Achensee, where primary paleoseismic evidence documents coseismic surface rupture of a lake-crossing thrust at ~8.3 ka BP. Furthermore, temporal and spatial coincidence of paleoseismic evidence with multiple rockslides at ~4.1 and ~3.0 ka BP reveals that severe earthquakes (ML 5.5–6.5; epicentral intensity VIII<I0<XI) have triggered the Fernpass and Tschirgant Rockslides, respectively.

U/Pb zircon, U/Pb allanite dating and petrology of the Ennstal Phyllite Zone (Eastern Alps)

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The Ennstal Phyllite Zone is a west-east striking tectonic unit paralleling the Enns valley east of Schladming in the Eastern Alps. The affiliation of this area to either the micaschist units (e.g., Wölz Complex, Rappold Complex) of the Koralpe-Wölz nappe system to its south or to nappes of the "Greywacke Zone" to its north and east is still in debate. In fact, due to similarities with phyllites of the "Greywacke Zone" in the north and phyllonitic garnet-bearing micaschists in the south, no clear lithologic boundary between these units is observable. A large east-west striking shear zone in the south suggests a tectonic boundary between the Wölz Complex and the Ennstal Phyllite Zone. In order to clear this debate and further constrain the tectonic evolution of these units, we present new LA-ICP-MS U/Pb age dating results and PT-calculations for the Ennstal Phyllite Zone as well as for the adjacent units of the Koralpe-Wölz nappe system. Metapelite samples were taken along multiple north–south striking valleys, which transect the Ennstal Phyllite Zone and the northernmost part of the Wölz Complex. Detrital zircon grains from two samples from the Ennstal Phyllite Zone and one sample from the northernmost part of the Wölz Complex were analyzed. In both samples from the Ennstal Phyllite Zone the youngest zircon population yields dates around 550 Ma, but other populations peak at ~625 Ma, 1,000 Ma, 2,000 Ma, 2,200 Ma and between 2,500 Ma and 2,950 Ma. The Wölz Complex sample shows the same peaks but contains two younger grains with an age of 460 Ma and 523 Ma. Therefore, a similar provenance for the investigated parts of both units is interpreted, these ages are, however, in contrast with Palaeozoic marbles within the Wölz Complex and the "Greywacke Zone". Furthermore, metamorphic allanite from two samples within the Ennstal Phyllite Zone and one sample from the Rappold Complex to the south were analyzed and dated with U/Pb LA-ICPMS. The Rappold Complex sample yields metamorphic ages of 276.6 ± 35.4 Ma for the allanite cores and 100.2 ± 1.5 Ma for the epidote rims. Two samples from the Ennstal Phyllite Zone yield metamorphic ages of 278.5 ± 6.3 Ma located in the southern part of this unit and 103.6 ± 6.4 Ma in the northern part. These ages are interpreted as close to prograde peak metamorphism with higher conditions during the Permian event based on textural features. Although the Ennstal Phyllite Zone shows a similar metamorphic history as the Rappold Complex during the Permian event (~275 Ma), the data point to a hanging-wall position of the Ennstal Phyllite zone during Eoalpine metamorphism (~100 Ma). Therefore, an affiliation of this area with units of the "Greywacke Zone" is suggested.

Zur Geschichte der Steirischen Landschaft

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Die Landschaft der Steiermark mit ihren Bergen, Tälern und Ebenen formte sich zwar über geologische Zeiträume, aber dennoch gab es erstaunlich große Veränderungen auch innerhalb der relativ kurzen Entwicklungszeit der Hominiden in den letzten fünf Millionen Jahren. Die ursprünglich über den Semmering in das Wiener Becken fließende Mur änderte ihren Verlauf allmählich nach Graz, die Enns floss noch über den Schoberpass in die Mur, viele der steirischen Vulkane existierten noch nicht und der Schöckl oder der Hochschwab waren noch keine Berge, sondern erhoben sich kaum merklich über das flach-wellige Hügelland. Der Vortrag illustriert Aspekte dieser verblüffenden Landschaftsentwicklung mittels spektakulärer Luftaufnahmen.

Data Mining – Rohstoffe der Zukunft!

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Der geologische Landesdienst hat vielfältige Aufgaben. Für die Erstellung zielsicherer, rascher und kundenorientierter Expertisen ist der Zugriff auf unterschiedliche geologische Daten unumgänglich. Eine Aufgabe des geologischen Landesdienstes ist es, diese Daten georeferenziert zu sammeln, zu archivieren und bei Bedarf der Bevölkerung und den öffentlichen Organen zur Verfügung zu stellen. Durch die Digitalisierung und technische Weiterentwicklung wurden in den letzten Jahren zahlreiche Instrumente, wie Mobilgeräte, Felderhebungsapplikationen, Software, Drohnen usw. beim Amt der Kärntner Landesregierung eingeführt. Durch diese Instrumente werden Daten selbständig gesammelt, ausgewertet und weiterentwickelt. Die vorhandenen Daten werden auch für verschiedene Forschungsprojekte herangezogen, um eine Verbesserung der Daten und Erweiterung des Inventars zu erzielen. Verschiedene Beispiele für die Sammlung, Auswertung und Anwendung der Daten in der Praxis und den Nutzen für die Bevölkerung werden vorgestellt.

Geo-energy exploration along the Austrian-Hungarian border in the western Pannonian Basin

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In the border zone between Austria, Hungary and Slovenia, the Miocene opening of the Pannonian Basin was characterized by extreme, large-magnitude upper crustal extension accommodated along low-angle detachment faults. Due to several unsuccessful wells drilled mostly in the 1980s, the hydrocarbon exploration potential is perceived to be negligible in this region. Therefore, only a limited set of vintage 2D reflection seismic sections is available in this part of the basin. These profiles date back to the 1970–1980s and no modern infill 2D seismic profiles, let alone 3D seismic surveys, were acquired since then. Moreover, due to the presence of the Iron Curtain prior to 1990, previous interpretation efforts could not achieve the proper subsurface correlation of major structural elements across the political border. In this study numerous exploration wells, drilled on both sides of the border, were re-evaluated and integrated with reflection seismic data to differentiate between the lower versus upper plates of major low-angle detachment faults in the Burgenland High area separating the Styrian Basin in the west from the Danube and Zala Basins in the east. The refinement of the previously proposed metamorphic core complex (MCC) style, ENE-WSW to NE-SW oriented high-strain extension model provides a modern understanding of magnitude of back-arc extension in this part of the Pannonian Basin system due to the early Miocene collapse of the Alpine orogen. Uplifted and subaerially exposed isolated basement highs along the basin margin (e.g., Sopron and Stadelberg Mts.) are now considered as useful analogues for similar subsurface structural highs related to lowangle detachment faulting (e.g. Minihof and Bük Highs, respectively). Very thick (up to 800 m) syn-rift coarse clastics in the hangingwall of prominent low-angle faults, penetrated by a few wells in the area (e.g., Szombathely-II and Csapod-1), developed in a fanglomerate facies providing reservoir target units for geothermal exploration. This case study is also an example of interpretation of less-than-ideal legacy 2D seismic data sets (30–50-year-old) reproduced in variable formats (i.e., hard-copies scanned and georeferenced without reprocessing or even vectorization). From a structural geology perspective, the early interpretation of these vintage seismic profiles was done in the 1980s without the appreciation of the existence of low-angle normal faults and MCCs, in general. The reassessment of the same data sets used in this study definitely benefited from the knowledge gained on these special structural features by both the academia and the petroleum industry over the past 40 years. Given the increasing focus on low-carbon energy solutions, the broader region needs a modern re-evaluation of the subsurface geo-energy potential not related to hydrocarbons. The willingness to interpret a collage of “old” 2D seismic reflection data could provide critical new insights in many other underexplored basin segments globally in the context of the energy transition. Oil and gas companies, given their unique subsurface legacy data sets, will play a key role in the re-assessment of “forgotten” basin segments worldwide.

Porosity and permeability of fractured Triassic carbonates forming the main ground water reservoirs of the 1st Vienna Water Main in the Schneeberg Massif (Lower Austria)

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Fractured, faulted and karstified carbonates are the most important aquifers providing tap water for the city of Vienna. Such hydrogeological reservoirs may be characterized by modified dual porosity-dual permeability models with karstic features forming the part of the model which is characterized by very high permeability and low total storage capacity. Fractured carbonate rocks with generally low permeability and low to moderate porosity constitute the second part of the model. Due to the large volume of fractured rock (several km³) the second part of the model provides most of the pore space for groundwater storage. While, by its high permeability and short groundwater transit times, the first part of the model is critical to the vulnerability of the aquifer, the second part determines the long-term storage capacity of the reservoir and the base flow of the tapped karstic springs. In this contribution we focus on the second part of the dual model by investigating the hydro-geologically important parameters porosity and permeability of fractured Triassic carbonates of the Kuhschneeberg in the catchment of the 1st Vienna Water Main (I. Wiener Hochquellenleitung). Analyses build on the structural-geological characterization of fractures of different origin, type and size. Fracture density, which is the key parameter governing both porosity and permeability of the aquifers, is assessed by a field-based semi-quantitative classification technique estimating the range of P32 values and in thin sections from flourolstained samples analyzed under UV-light. Porosity was measured by immersion techniques and an automated Vinci 700 Gas Porosi Permeameter. The latter was also used to determine Klinkenberg permeabilities from plug samples at confining pressures between 400 and 6,500 psi. Measurements of porosity/permeability were conducted to assess the reduction of porosity/permeability with increasing overburden of the aquifers, which is an important effect in the analyzed catchments where springs emerge at altitudes about 1–1.5 km below the elevation of the karst plateaus. The results of our analyses reveal porosity values between about 0.5 and 7 % and a wide range of Klinkenberg permeabilities between about 0.001 to 2 mD. Data further show that the reduction of porosity and permeability by overburden is a relevant effect even at low confining stress/overburden. The largest reduction applies to rocks with high fracture density and high fracture porosity. Rocks in which porosity is carried by other types of pores (e.g., cataclasite) suffer much less porosity/permeability reduction. Porosity-permeability (Phi-K) correlations show no apparent influence of increasing confining stress.

Blast vibration prediction

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In order to limit ground vibrations to sensitive areas in the vicinity of a mine, it is essential to predict peak ground velocity (PGV) for production blasts. A general formula can be used to relate the PGV to the offset between sensor and production blast with a spatial decay exponent b and the maximum charge weight per delay (q) with a charge exponent c. To calibrate this equation a wide variation of offsets as well as a wide variation of maximum charge weights is desirable. Both parameters are often limited in mines due to the size of the mine or to production constraints. Therefore, the inversion can be very unstable. To get around this problem, mining operators use the scaled distance (SD) approach. The SD is the offset divided by some power of q. There are various empirical formulas and they are just distinguished by the exponent m of q. This exponent m typically ranges between 1/3 and 2/3. In the SD approach the charge exponent c becomes some ratio of the exponent b. This ratio seems to be arbitrary and we did not see a physical justification for that. In mining practice this does not matter if just the accuracy of the prediction is important. The mining operator in the particular mine for this study uses the USBM SD approach with a ratio of m = 0.5. We explored other strategies to calibrate the general equation and, we compare them with some key performance indicators like the root mean square (rms) residual and the coefficient of determination (R^2). One of the strategies are subset inversions where we are able to drop one of the exponents as a constant and invert for the remaining exponent. As an alternative to subset inversions we also jointly invert all data to constrain global b and c values. For this study we used data of 55 regular production blasts recorded with an array of 81 seismic three-component stations at 119 different receiver sites. Half of the stations are located on top of the loose sediments of the valley fill and hillside slides. The remaining stations are located within the mine on hard rock. The sensors are acceleration MEMS with a flat amplitude response function that we integrated to get ground velocities. The final derived decay exponent b was higher than expected due to spherical spreading of the wavefronts. The complexities of the subsurface and topography make it difficult to ascertain b to a physically reasonable range. The derived charge exponent c was close to the expected value of 0.5, assuming that charge weight is proportional to seismic energy. This value could be suggested as a global value, independent of the specific site. Both exponents are not correlated with each other. Overall, the used USBM SD method was not very suitable in terms of data fit. This research was partially funded by the European Union’s Horizon 2020 research and innovation programme under grant agreement 730294: Sustainable Low Impact Mining (SLIM). Peter Schimek from the mine operator VAE Erzberg provided crucial support for the station deployments and the coordination with the blasters.

Subduction in a vessel: petrology of eclogite-tempered ceramics from the Kiechlberg (Thaur, Tyrol)

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In the course of this investigation ceramic fragments of the Neolithic and Early Bronze-Age settlement site at the Kiechlberg in Thaur (Tyrol, Austria) were petrographically examined. The ceramic fragments, which mainly represent wall parts of ceramic vessels, form a glassy matrix, which contains different kinds of tempers. Subordinate recycled ceramic fragments as well as slag temper occur in the ceramics. The addition of temper components reduces stress cracks during drying and firing and increases the fire resistance of the vessels. However, in this investigation for the first time eclogite fragments occur as temper. Since river rocks and especially metamorphic rocks are very difficult to crush, it can be assumed that they were heated in a fire and quenched with cold water ("firecracking"). The ecolgites show a strong amphibolite-facies retrograde overprint and show characteristic symplectite structures. The eclogite-facies mineral assemblage is garnet + omphacite + epidote + amphibole + quartz. Garnet contains omphacite inclusions and omphacite has mostly been retrogressed to amphibole + diopside + plagioclase. Chemically the amphiboles can be classified as magnesiohornblende, tschermakite or edenite. Calculation of the P-T conditions of the eclogites using the mineral assemblage garnet + omphacite + epidote + amphibole + quartz and the program THERMOCALC v.3.21 yielded 680 ± 36 °C and 1.7 ± 0.01 GPa. Typologically these ceramic fragments have been assigned to the Altheim culture (ca. 3700–3300 BC) of southern Bavaria (Töchterle, 2015). Geographically this indicates that the provenance area of the eclogites temper is probably the Bohemian Massif or the Münchberg Gneiss Massif from the western margin of the Variscides. Another possibility is that the ceramics were made on site at the Kiechlberg and the eclogites were obtained from the river Inn. In this case eclogites from the central Ötz valley could have been used, which has been demonstrated by the use of eclogite hammer stones in the Lower Inn Valley in prehistoric times. More probable, however, is, since prehistoric trade between the Bavarian alpine foothills and Tyrol/South Tyrol took place, which was via the Inn valley, that the ceramics were made in the southern Bavarian area. Based on the mineral assemblage these eclogite temper fragments match petrographic observations from the Bohemian Massif, the Münchberg Gneiss Massif and the central Ötz valley, where latter two localities match even better. The mineral assemblage of the Münchberg eclogites matches that of the eclogite temper fragments in the Kiechlberg pottery very well and the obtained P-T conditions agree with estimates from the Münchberg Gneiss Massif. Why these eclogites were used as temper remains unknown but eclogites could be very suitable as temper, Because of their low thermal expansivity at high temperatures. Nonetheless the occurrence of eclogite temper in ceramic fragments represents a unique find in Bronze Age pottery but due to the petrographic similarity of eclogites in general, the geological provenance of these eclogites cannot be exactly determined solely on petrographic observations.

Evidence for decreasing impact-evoked pressure (UHP) conditions during frictional fusion along different shear planes in the Tsergo Ri (Langtang Himal, Nepal) rockslide

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The Tsergo Ri rockslide represents one of the world`s biggest rockslides in crystalline rocks (original volume: 1,010 m^3). The mass movement comprises migmatites, leucogranites, biotite-feldspar orthogneisses and paragneisses (Weidinger et al., 2014). During mass-wasting, frictionites and microbreccias formed at the base of the rockslide (Heuberger et al., 1984). The frictionite is mainly composed of a glassy matrix containing sparsely biotite, quartz, and abundant plagioclase and K-feldspar. Biotite locally shows a transformation to spinel + glass in highly glassy microdomains. Fe-rich layers in the glass indicate complete melting of biotite-rich layers of the protolithic biotite-bearing orthogneiss. Locally, quartz grains are rimmed by a thin layer of SiO_2 glass (lechatelierite). In the course of this study, micro-Raman spectroscopy was performed on deformed quartz grains from temporally different shear planes within the rockslide. Investigations by McMillan et al. (1991), Fritz et al. (2011) and Kowitz et al. (2013) have shown that shocked quartz shows a shift in the major Raman modes towards lower numbers with increasing pressures. Related to this samples containing quartz crystals with and without lechatelierite rims in the Tsergo Ri frictionites have been investigated. Raman mapping of quartz grain areas was prepared using a HORIBA Jobin Yvon LabRam HR800 micro-spectrometer equipped with a 30 mW He-Ne laser (633 nm emission). Weidinger et al. (2014) describe a temporal sequence of shear planes within the rockslide. Basal or primary shear planes formed during rockslide motion. Secondary shear planes formed because of transient differential motions dictated by inner shear and these secondary shear planes formed within the weaker unit of the Tsergo Ri rockslide in Nepal. Tertiary shear planes occur as sub-vertical internal discontinuities within the deposit of Tsergo Ri rockslide and are attributed to form upon collision of the moving rockslide mass with large topographic obstacles such as mountain flanks. Micro-Raman spectroscopy of `normal` quartz yielded an intense A1 Raman mode at 464 cm^{-1}, whereas quartz without lechatelierite rims shows a shift of this band down to 461.5 cm^{-1}. The highest shifts down to 460.5 cm^{-1} occurred in relict quartz grains rimmed by lechatelierite from the primary shear plane. It is also noteworthy that these grains show an internal gradient of Raman shift of up to 3 cm^{-1} from the core (463.5 cm^{-1}) to the rim (460.5 cm^{-1}) to just below the lechatelierite rims. Slightly less shift occurred in quartz from the secondary shear plane down to 462 cm-1 and almost no shift occurred in the tertiary shear planes. The completely molten granitic matrix and the breakdown of biotite to spinel + melt indicates minimum temperatures of 900–1,000 °C and Sanders et al. (2020) showed that the shifted A1 mode of quartz is stable only below 1,100 °C, thus giving an upper limit of the temperature range. The observed Raman shift of the A1 mode and the presence of lechatelierite strongly suggest that a pressure of possibly > 26 GPa was attained in the primary shear planes and 22–26 GPa in the secondary shear planes and most likely pressures < 1 GPa in the tertiary shear planes.

Mineralogische Untersuchungen (XRD und DTA-TG) zur Zusammensetzung und zum Brennverhalten ausgewählter Tonproben hinsichtlich archäologischer Fragestellungen zur lokalen Keramikproduktion

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Im Tiroler Raum wurden bereits in der Jungsteinzeit Gefäße aus Keramik verwendet und wahrscheinlich aus lokalem Ton hergestellt. Ab der Römerzeit wurden die Tiroler Tonvorkommen zur Ziegelherstellung genutzt (z.B. römische Ziegelei beim „Greiderer am Inn“ in Angath). Der mineralogische Vergleich geborgener Keramik mit den in Frage kommenden, in der näheren Umgebung anstehenden Rohtonen gibt oft Hinweise darauf, welche Gefäße lokal hergestellt und welche als Import zu deuten sind. In diesem Zusammenhang lassen sich auch herstellungsspezifische Merkmale wie in etwa die Höhe der Brenntemperatur ermitteln. In den letzten Jahren wurden 7 bis 10 verschiedene Tonvorkommen im Tiroler Unterland beprobt. Auf Basis dieses Materials können verschiedenste naturwissenschaftliche Analysen durchgeführt werden. Als Methoden bieten sich hierfür vor allem Differenz-Thermoanalyse/Thermogravimetrie/Massenspektrometrie (DTA-TG/MS), Pulver-Röntgendiffraktometrie (XRD) und Hochtemperatur-Röntgendiffraktometrie (HT-XRD) an. Da die Zusammensetzung der Tonproben und die damit verbundenen Eigenschaften des Materials für den Tiroler Raum noch größtenteils unerforscht sind, wird hier eine wichtige Grundlage für eine umfassende Charakterisierung der Ausgangsmaterialien für die prähistorische Keramik im Unterinntal betrieben. Im Zuge der ersten Untersuchungen wurde eine Rohtonprobe aus Thaur mittels XRD und DTA-TG/MS untersucht. Die Probe stammt aus der unmittelbaren Nähe eines Areals, das noch heute als „Lehmgrube“ bezeichnet wird und auf dem im 19. Jahrhundert eine Ziegelei stand. Der dort natürlich vorkommende Ton eignet sich nicht nur zur Herstellung von Ziegeln, sondern auch zur Anfertigung von prähistorischer Keramik. Eine XRD-Analyse der Tonprobe ergab die folgende Mineralparagenese: Chlorit + Muskovit + Dolomit + Kalzit + Quarz. Um das Verhalten des Tons beim Keramikbrand zu untersuchen, wurde eine DTA-TG/MS bis 1.100 °C in Luft durchgeführt. Bis ca. 600 °C zeigt sich ein Massenverlust von ca. 4.4 %, der in 4 unterscheidbaren Ereignissen auftritt (Maxima bei ca. 70, 143, 258 und 553 °C), welche per MS deutlich als Wasserabgabe identifiziert werden können. Überschneidend mit dem letzten Maximum bei 553 °C, setzt der Zerfall der Karbonate ein und erreicht bei 793 °C ein Maximum, ab 810 °C ist die Karbonatzersetzung beendet. Der Massenverlust durch CO_2 (ab 600 °C) macht ca. 16 % aus. Mittels XRD wurde die folgende Endparagenese ermittelt: Åkermanit + Diopsid + Periklas + Wollastonit + Muskovit + Quarz. Um das Verhalten des Tons beim Brand ohne Sauerstoff zu untersuchen, wurde ein Experiment in He-Atmosphäre durchgeführt. Dieses Experiment ist im Wesentlichen durch einen größeren Massenverlust im Bereich der Karbonatzersetzung (ca. 22 %) gekennzeichnet. Mittels XRD wurde in diesem Experiment die folgende Endparagenese ermittelt: Åkermanit + Larnit + Periklas + Hatrurit + Muskovit + Quarz. Der erhöhte Massenverlust in He-Atmosphäre ist entweder auf die Inhomogenität des Probenmaterials (variierender Karbonatanteil) zurückzuführen, oder auf gleichzeitige Oxidationsprozesse im Luft-Experiment, welche dem Massenverlust entgegenwirken. Weitere Versuche sind in Verbindung mit petrographischen Untersuchungen von bronzezeitlicher Keramik aus dem unterinntaler Raum geplant.

High-grade fluid/rock interactions in metapelites: theoretical and observed phase relations and the behavior of accessory phosphate phases in the Kottavattam charnockites (S-India)

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Charnockitization is a fluid-driven process that takes place in rocks from the lower crust. During this process an externally-derived fluid interacts with the rocks and mineralogical and textural transformations occur within the rocks. The most important feature is the breakdown of water-bearing minerals like hornblende and biotite to pyroxenes due to the influx of low a(H_2O) fluids. In the course of this Bachelor Thesis, the in-situ charnockitisation in felsic granulite samples from Kottavattam, S-India was investigated using polarizing microscopy, micro-X-ray fluorescence and electron probe microanalysis. Typical textures associated with charnockitisation such as the replacement of biotite by orthopyroxene (now replaced by chlorite/smectite), the formation of myrmekites and monazite exsolutions in apatite could be identified. The observed phase relations are compared to thermodynamic calculations using the program Domino-Theriak (de Capitani & Petrakakis, 2010). In this investigation six samples of a charnockite rock sample (Opx-bearing granulite) from India (Kottavattam) were investigated. The XRD and XRF investigations show that the feldspar content increases sharply from Kotta-1 (unaltered) to Kotta-6 (charnockite). Quartz, biotite and garnet contents decrease from samples Kotta-1 to Kotta-6. Responsible for these changes in mineral composition are two mineral reactions: Garnet + Quartz = Plagioclase + Orthopyroxene (CFASH) and Biotite + Quartz = K-Feldspar + Orthopyroxene + H_2O (KFASH). Apatites with inclusions of monazite were observed. The inclusions show two patterns. Monazite and/or xenotime inclusions without discernible orientation within the apatite and those, which occur along cracks within the crystal. Overall, two generations of monazite and 3 generations of apatite formed. In the first stage, apatite is depleted in (Y + REE) and the first generation of monazite randomly orientated within apatite. Contemporaneous a second generation of apatite forms depleted in (Y + REE). In stage II another generation of monazites and/or xenotime formed along cracks due to solubility and recrystallization of apatite. Apatite along these surfaces is also (Y + REE) depleted hence forming the 3rd apatite generation. Calculations using Domino-Theriak show that the mineral assemblage garnet, 2 feldspars, biotite, magnetite and quartz is preserved in samples Kotta-1 to Kotta-4. In the calculations of samples Kotta-5 and Kotta-6, orthopyroxene forms. However, the samples are retrogradely altered to such an extent that their bulk composition probably no longer corresponds to the initial bulk composition. Similar to the XRD analysis the calculations show that for samples Kotta-1 through Kotta-6 biotite and garnet contents decrease and feldspar contents increase with increasing charnockitization. In the calculated pseudosections the lowered a(H_2O) necessary to stabilize orthopyroxene is 0.75 in sample Kotta-1. In samples Kotta-2 through Kotta-4, a(H_2O) ranges from 0.05 to 0.1. In samples Kotta-5 and Kotta-6, the initial chemistry has already changed so that only orthopyroxene is stable instead of biotite. Overall, a(H_2O) varies strongly between the samples between 0.7 and 0.05 which could be due to local differences in fluid composition. The data obtained agree very well with the studies of Raith & Srikantappa (1993) on the same rocks.

Uplift and exhumation of the Alpine foreland

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The foreland basin of the Alps is among the best-studied foreland basins in the world. Its stratigraphy, as well as the structure of the adjacent foreland fold-thrust belt are well established. However, the basin has experienced a late-stage phase of exhumation, of which timing, spatial extent and magnitude are still poorly resolved. Understanding this youngest phase of basin evolution is required to infer the underlying driver of exhumation. In particular, it may help gaining insights on the late-stage tectonic evolution of the Alpine mountain belt in the light of a potential change in slab dynamics in the Western and Eastern Alps. In this contribution we will show new low-temperature thermochronological data from the foreland basin, as well as the fold-thrust belt, in combination with previously published data. Interestingly, interpreting the lowtemperature thermochronolgical data is not straightforward and may be partly influenced by fluid flow. Nevertheless, a distinct exhumation pattern can be deduced, showing a different signal in the Western and the Eastern Alps, respectively. We infer that while the foreland fold-thrust belt shows a signal of plate convergence, exhumation of the basin itself is largely triggered by mantle dynamics that are variable along strike of the orogen.

Die Fossiliensammlung des Bozner Privatgelehrten Georg Gasser (1857–1931): Ziele und Aufbau einer historischen Sammlung

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Um die Wende vom 19. zum 20. Jahrhundert stellte der Privatgelehrte und naturwissenschaftliche Autodidakt Georg Gasser (1857–1931) eine breit angelegte Naturaliensammlung zusammen, welche u.a. tausende von Mineralien, Fossilien, Tierpräparaten usw. umfasste und bald weit über die Grenzen Tirols hinaus bekannt wurde. Nach Jahrzehnten der Verwahrlosung und teilweisen Auflösung, die auf den Tod Gassers folgten, ging die Sammlung schließlich in den Besitz des Landes Südtirol über, wo sie den Grundstock des 1997 eröffneten Naturmuseums in Bozen bildete. Gasser war zu Lebzeiten vor allem als Mineraliensammler bekannt. Als solcher versuchte er, die Mineralvorkommen seiner Heimat systematisch zu dokumentieren, was sich auch in seinem Werk „Die Mineralien Tirols“ (1913) niederschlägt, dem seinerzeit vollständigsten Werk über die Mineralien des Tiroler Alpenraums. Dementsprechend ist auch die historische Forschung zu Georg Gasser bislang hauptsächlich auf seine mineralogischen Interessen fokussiert gewesen. Die mehr als 3.000 Exemplare zählende Fossiliensammlung Gassers hat hingegen bis heute wenig Beachtung gefunden. Erst in den letzten Jahren hat das Naturmuseum Südtirol im Rahmen eines eigenen Forschungsprojektes begonnen, die Fossilien der Sammlung Gasser zu inventarisieren, dokumentieren und systematisch zu überarbeiten. Dabei wurde auch historischen Fragestellungen nachgegangen und versucht, Gassers Kontakt zur paläontologischen Forschung seiner Zeit, aber auch seine Bezugsquellen und nicht zuletzt die Ziele zu rekonstruieren, die Gasser beim Aufbau seiner Sammlung verfolgte. Eine Auswertung der Fundortangaben in Gassers Sammlungskatalogen ergibt, dass etwa 30 % aller Fossilien aus den damals zu Österreich gehörenden alpinen Gebieten stammt (etwa 25 % aus „Tirol“ im historischen Sinn, also Nord-, Süd-, Osttirol plus Trentino; die restlichen 5 % aus anderen Gebieten wie z.B. Salzburg, Steiermark und Oberösterreich), weitere 10 % aus nicht alpinen Regionen Österreich-Ungarns (z.B. Niederösterreich, Wiener Becken, Banat, Böhmen), 27 % aus Gebieten des damaligen Deutschen Reiches, 2 % aus damals zu Italien gehörenden Gebieten, 2 % aus anderen europäischen Ländern und 5 % von außereuropäischen Ländern. 16 % sind Fossilien aus den Tertiärbecken in Österreich, Deutschland und Frankreich; hier wurde nicht nach Herkunftsgebieten differenziert. 8 % sind unbekannter Herkunft. Zusammengerechnet 67 % der Sammlung stammen also mit Gewissheit aus dem damals deutschsprachigen Raum; diese Ziffer steigt sogar auf etwa 75 % bis 80 % an, wenn die Fossilien aus dem marinen Tertiär Europas mitgerechnet werden. Fundorte in relativ fernen Gebieten wie Schlesien oder Norddeutschland sind mehr vertreten als Funde aus dem geographisch nahen Norditalien. Dies belegt, dass die Zugehörigkeit zum deutschen Sprachraum Gassers Auswahl mehr beeinflusste als die geographische Nähe zu Bozen. Dennoch darf nicht übersehen werden, dass etwa ein Viertel der gesamten Sammlung aus Tirol stammt, wobei die Sammlung aus heutiger Sicht durch Belege aus inzwischen erloschenen Fundorten an Wert gewinnt. Die Fossiliensammlung Georg Gassers kann daher als breit angelegte didaktische Belegsammlung beschrieben werden, deren Ziel es war, als damals einzige öffentlich zugängliche paläontologische Sammlung in Südtirol dem Museumsbesucher einen Eindruck von den Lebensformen im Verlauf der Erdgeschichte zu vermitteln. Funden aus Tirol wurde dabei immerhin ein besonderes Augenmerk geschenkt.

Modern garnet quality control: Micro-XRF and micro-computer tomographic investigations on Zillertal garnet raw products and jewellery pieces

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Micro-XRF (X-Ray Fluorescence) is a powerful tool for the mineralogical and geochemical analysis of garnet raw products and jewellery. This method allows visualization of large-scale chemical zoning and identification of mineral inclusions in garnet, since electron probe microanalysis (EPMA) investigations are restricted to small areas of only several 100 µm. In addition, especially the non-destructive analysis and uncomplicated sample preparation are of enormous importance. Even simple qualitative analyses, such as elemental distribution maps or point analyses, give insight into chemical and geochemical differences between different garnets used in a piece of jewellery. In one piece of jewellery, at least three chemically different types of garnet could be discerned. Furthermore, these analyses can be used for quantitative chemical provenance investigations. To get quantitative results, two different methods are available, namely fundamental parameters method and the use of well characterized standards. Due to the formation conditions of the different garnets used in jewellery, chemical differences are visible in the measurements and allow statements to be made about the provenance. For instance, the difference between Zillertal and Bohemian garnet lies in the high Cr-contents of the latter and the high Fe-contents of the former. Another advantage of using the micro-XRF is that compositional zoning of large (several mm to cm) garnet crystals using major (Ca, Mn), minor (P, Ti) and trace (Y) elements can be visualized. This makes it also possible to distinguish between garnets from Zillertal, Radenthein, Ahrntal and Bohemia, as they formed under different P-T conditions as well as in different host rocks. The use of micro-computer tomography to characterize garnet quality, with respect to inclusion patterns, is particularly noteworthy and a novel technique for assessing garnet quality. The advantage in contrast to thin section analysis is that it is basically a non-destructive method and that there is a spatial distribution of quality characteristics such as chemical zoning and mineral inclusion assemblages, which can be visualized in 3D. First investigations were carried out on a garnet from a batch of “good quality” materials. The investigations revealed that the garnet contains numerous inclusions which in the end do affect its quality as a semi-precious gemstone.

New P-T-t constraints on the metamorphic evolution of the garnet-chlorite schists from the Roßrugg (Zillertal core, Tauern Window, Tyrol): home of the Zillertal jewellery garnets

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The mineral garnet has been an important raw material for jewellery since Early Medieval times and it is therefore of great interest to the archaeological sciences. In the alpine region, garnet, especially the variety almandine ($Fe_3Al_2Si_3O_{12}$), is still used today as traditional costume jewellery. Garnet mining started in the Eastern Alps around the middle of the 18th century in the Ziller Valley (Zillertal), or more precisely the area of the Roßrugg in the Zemmgrund, which served as a major source of garnet raw materials. These garnets from the Ziller Valley and furthermore from the Ahrn Valley (South Tyrol), Radenthein (Carinthia) and the Czech Republic are subject of the project “Garnet from the Ziller Valley – Cultural heritage of an East Alpine semiprecious stone industry as reflected in interdisciplinary research”, which is funded by the Austrian Academy of Sciences (ÖAW). Geologically garnet-chlorite schists (garnet + chlorite + muscovite + biotite + plagioclase + quartz + rutile + apatite) at the Roßrugg occur along shear zones inside the Zillertal core (Tauern window) which formed during the Alpine orogeny. Besides the detailed geochemical characterization (e.g., EPMA, micro-XRF and determination of trace element zoning with LA-ICP-MS) of 21 different garnet localities throughout the Ziller Valley, geochronological investigations of garnets from two Roßrugg samples (6E and 3W) are carried out. Due to the paucity of robust age data concerning garnet formation in the Tauern Window, a first attempt using Lu-Hf dating of garnet was undertaken and yielded an age of 32.35 ± 0.22 Ma. This age fits into the time span between the formation of the Venediger Duplex and the “Tauernkristallisation”. In addition to age dating, thermodynamic modelling using pseudosections and averagePT calculations was done. AveragePT conditions using the program THERMOCALC 3.50 resulted in 550–560 °C and 0.8–0.82 GPa. Pseudosection modelling was done using THERIAK-DOMINO and two databases (tcdb55c2d and td-ds62-mp50-03). Depending on the database used, the outcome resulted in different mineral assemblages. However, the observed assemblage is in agreement with the results using the most recent td-ds62-mp50-03 database. Calculation of garnet isopleths using the program Perplex yielded garnet growth with decreasing pressures (ca. 0.9 GPa in the core and 0.8 GPa in the rim) and increasing temperatures (560 °C in the core and 590 °C in the rim). The obtained garnet ages agree with the existing age data of the Alpine metamorphic event and indicate that the time span between Alpine eclogite formation and subsequent “Tauernkristallisation” is rather short.

Stratigraphy of the Anthropocene

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The Anthropocene Working Group (AWG) of the Subcommission on Quaternary Stratigraphy, a part of the International Commission on Stratigraphy, is exploring and evaluating stratigraphic successions, as potential stratotypes, in order to facilitate a formal submission of a GSSP (Global Boundary Stratotype Section and Points) proposal, from which a specific year for the onset of the “geological” Anthropocene will be established. The aim is to seek ratification of the Anthropocene as a geological epoch starting in the mid-twentieth century. Stratigraphic records, including a range of novel materials, geochemical and biological signals spanning the mid-twentieth century interval of unprecedented human activity and industrialisation, are being gathered several international teams of scientists, working currently on twelve sections from around the planet. Twelve sites are investigated for a possible GSSP for the Anthropocene epoch, on basis of annually varved sediment cores, coral, peat and speleothem layered records, and other features like artefacts: corals from Flinders Reef, Australia and the West Garden Flower Bank Reef, USA; sediment cores from Searsville Reservoir, USA, Crawford Lake, Canada, Sihailongwan Lake, China, San Francisco Estuary, USA, Beppu Bay, Japan, East Gotland Basin, Baltic Sea, Germany, the Palmer ice core from the Antarctic Peninsula, cores from Śnieżka Peatland, The Sudetes, Poland, Antarctica, a stalagmite from Ernesto Cave, Italy, and finally a section from an archaeological excavation at Karlsplatz, Wien Museum, Vienna, Austria. While the compilation of stratigraphic data to define a new epoch is as old as the science of geology, the demarcation of one within living history that signifies human activity as a global geological agent is unparalleled. Similarly, there is no precedent of a stratigraphic formalisation process being pivotal to the framing of so much contemporary social, ecological, artistic, historical and political thought. In May 2022 along with the online publication of the results and data, an exhibition including a discursive and performative programme was established in the Haus der Kulturen der Welt (HKW) in Berlin as a public forum for the scientific, cultural and socio-political impact of the stratigraphic research carried out by the international research project on the Anthropocene.

Stratigraphy of the Turonian-Coniacian boundary interval in the Gosau Group of Gams, Styria

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At Gams bei Hieflau, Styria (Northern Calcareous Alps of Austria), the presence of upper Turonian ammonites, inoceramids, micro- and nannofossils was reported from previous work, e.g., by Herbert Summesberger and Heinz Kollmann, including the type locality of the ammonite *Barroisiceras haberfellneri* (Hauer) at Radstatthöhe, between the villages of Mooslandl and Gams, within marls of the Grabenbach Formation. A renewed field survey in the framework of a Bulgarian-Austrian WTZ project indicated several new biostratigraphic results, based on bivalves, dinoflagellates, and calcareous nannofossils along road cuts and artificial outcrops NE of Radstatthöhe. The presence of *Barroisiceras haberfellneri* and the bivalve Didymotis attests for the interval of uppermost Turonian to lowermost Coniacian, where Didymotis events are known from several European sections. Small-sized representatives of the genus Didymotis were collected, which are preserved as internal moulds, only rarely with shell fragments attached. The specimens are almost equilateral, ornamented with relatively thick, widely spaced, rounded commarginal rugae. The radial ornamentation is visible in one specimen only. The sampled small-sized Didymotis with slender or no radial ornamentation are very similar to the Didymotis I morphotype considered to be part of the Didymotis I event in the upper Turonian *Mytiloides scupini* Zone at Salzgitter-Salder (GSSP for the base of the Coniacian). Based on this sparse Didymotis record we assume a late Turonian age (?*Mytiloides scupini* Zone) for the studied interval. One test sample from the Turonian-Coniacian boundary interval at Gams yielded a dinocyst association of moderate abundance and preservation. The association includes the following taxa: *Achomosphaera ramulifera*, *Canningia glomerata*, *Dinopterygium alatum*, *Isabelidinium cooksoniae*, *Kleithriashpaeridium readei*, *Raetiadinium truncigerum*, *Oligosphaeridium pulcherrimum*, *Spiniferites ramosus*, *Pterodinium cingulatum* and *Exochosphaeridium majus*. The concurrent presence of the dinocyst species *Raetiadinium truncigerum*, *Oligosphaeridium pulcherrimum* and *Canningia glomerata* marks an age not older than late Turonian for the sampled succession, compared to the data from the recently established Turonian/Coniacian GSSP boundary stratotype at Salzgitter-Salder, Germany. Nannofossil data at Radstatthöhe report the presence of *Marthasterites furcatus* and *Lithastrinus septenarius*, indicating nannofossil standard zones CC13 and UC9 (upper Turonian–lower Coniacian). The absence of *Zeugrhabdotus biperforatus* may further indicate nannofossil subzone UC9a. Additional detailed stratigraphic investigations are planned in cooperation with the Geopark Steirische Eisenwurzen and in the framework of UNESCO IGCP-710.

Mineralogical and geochemical characterization of the Dolostone Ore Formation, Kunene region, Namibia

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In 2012 Namibia's first potential cobalt-copper deposit – the Dolostone Ore Formation (DOF) – was discovered close to Opuwo (Kunene region, Namibia). The Kunene region is located in the Eastern Foreland of the Neoproterozoic Kaoko Belt, which is the northern branch of the Damara Orogen and formed during the amalgamation of Gondwana. The Kunene region is characterized by a thick Neoproterozoic sedimentary succession deposited during the break-up of Rodinia within a terrestrial to marine environment and was affected by two global glaciations (Sturtian and Marinoan glaciation). The DOF has an E-W extend of ca. 50 km and is a ca. 30–70° dipping, sediment-hosted, stratiform/stratabound mineralization with a sharp footwall contact and a gradual hangingwall contact. The DOF is bound to pre-Sturtian low-grade metamorphosed dolomitic marlstone underlain by terrestrial sediments in the west evolving to carbonate richer rocks and shales in the east. According to the cobalt and copper concentrations, the ore horizon is divided into a high grade DOF, a Wider DOF, a Cu-rich Wider DOF, and a low grade Wider DOF. The thickness of the highly mineralized horizon varies from 4 to 8 m and it thickens towards the east. In addition to the geochemical characteristics, these horizons also show differences in mineralization types. Ore minerals are predominantly linnaeite, cobaltite, Co-rich pyrite, chalcopyrite, and sphalerite. Cobalt is hosted primarily in linnaeite and a Co-rich pyrite (ca. 2.25 mass% Co) and Co-enriched sphalerite (< 2.70 mass%). According to its Co:Ni ratio linnaeite refers to a Co-rich grimmite ($Ni_{0.6-0.7}Co_{2.3-2.4}S_4$). EPMA mineral chemical analyses document slight differences in the Fe, Ni, Co and Cu concentrations of various generations of ore minerals (i.e., pyrite, pyrrhotite, chalcopyrite, sphalerite, linnaeite, and cobaltite). The ore minerals are found in several mineralization types: (1) irregular to clustered disseminated mineralization, (2) mineralized nodules and concretions, (3) mineralization within strain shadows, (4) veinlet hosted mineralization of different generations, and (5) "DOF events", which are distinctive structures with a ductile and/or brittle deformation and seem to be a combination of several mineralization styles. In general, irregularly distributed ore minerals pyrite, pyrrhotite, chalcopyrite, sphalerite and linnaeite are most frequent. Mineralization is assigned to four paragenetic stages thought to have mainly formed during the Damara Orogeny (560–550 Ma): Stage I) early stage with framboidal pyrite, Stage II) Co-Ni-Fe stage that formed during the main deformation event and includes mainly Co-rich pyrite, pyrrhotite and linnaeite, Stage III) Cu-Zn-Fe-(Co-Ni) stage which is characterized by veinlets containing quartz, chalcopyrite and sphalerite postdate the former stages, and Stage IV) with the formation of decomposition structures within pyrite, pyrrhotite and linnaeite. Raman spectroscopy of carbonaceous material yielded a metamorphic peak temperature of 345 ± 32 °C indicating also hydrothermal alteration in the DOF and in the Cu-rich Wider DOF. The Cu-rich Wider DOF is characterized by a high concentration of quartz-rich veinlets formed during Stage III of the paragenetic sequence. Mineralization in the Kunene region show many similarities to the sediment-hosted Cu-Co deposits in the Central African Copper Belt but there are also marked differences (e.g., lack of evaporites in the stratigraphic sequence).

A study on the prediction of critical water saturation of shale when it has sealing capacity

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Shale itself contains a certain amount of water, and the water reduces the seepage ability of shale. With the increase of water saturation (SW), the water in shale pores will change from water film to capillary water. Capillary water can block seepage channels, which gives shale the ability to seal. The current research work on shale gas preservation and carbon dioxide capture, utilization, and storage (CCUS) pays great attention to this capillary sealing phenomenon in shale, so the corresponding critical water saturation (CSW) is worth studying. However, the pore system of shale is complex. It contains both organic and inorganic pores, but due to the obvious difference in hydrophilicity between the two, water is mainly hosted in the inorganic pores. And shale has strong heterogeneity. The shale with different total organic carbon content (TOC) has different development degrees of organic pores and inorganic pores. Therefore, the TOC and pore structure pose a great challenge to predict the CSW of shale. In our study, the TOC of the Silurian Longmaxi Formation shale samples was tested first. Then, based on kerogen preparation technology and pore structure characterization methods, CO_2 and N_2 gas isotherm adsorption experiments were carried out on shale and its kerogen samples. Then, the pore volumes and proportions of organic pores and inorganic pores were calculated based on the data obtained from the isotherm adsorption experiments. Finally, the CSW of shale simples was calculated by the sum of the water content of organic and inorganic pores according to the defined boundary conditions of the geological model. The results show that the TOC of shale samples range from 0.89 % to 5.10 %. The pore volume of shale its kerogen samples range from 0.0185 to 0.0298 cm^3/g and 0.0020 to 0.0179 cm^3/g. With the increase of organic matter content, the pore volume of shale and its kerogen show an increasing trend. The proportion of organic pores ranges from 10.19 % to 67.63 %, and the proportion of inorganic pores ranges from 32.37 % to 89.81 %. The proportion of organic pores and inorganic pores both have a good correlation with TOC. This means that the shale with higher TOC has more organic pores and less inorganic pores. And the CSW of shale samples range from 19.42 % to 53.88 %, which is positively related to TOC. According to the fitting of CSW and TOC, a general formula for calculating critical water saturation when shale has sealing ability was obtained. This research provides effective guidance for predicting the CSW of shale when it has the sealing ability, and it deepens the understanding of the occurrence characteristics of water in shale and its influence on the sealing ability of shale. Usually, due to changes in depositional environment, the TOC of shale in a certain set of formations often has obvious changes. Therefore, in the actual geological model, the CSW of shale at different depths is different. Thus, this study can be used to further describe the preservation conditions of the geological model in more detail, so as to improve the theory of shale gas accumulation and guide the field work of shale gas exploration and development and CCUS.

The CaO-MgO-CO_2-H_2O-organo system revisited: New insights from thermodynamic modelling of mineral phase transformations

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The refractory industry is increasingly using carboxylic acids, such as acetic and citric acid, to control the hydration behaviour of cast products containing periclase [MgO]. The reaction pathways of MgO dissolution and subsequent Mg-aquo/organo complexation, as well as the precipitation/re-dissolution of Mg-organo salts versus the hydration of MgO to form brucite [$Mg(OH)_2$] are still poorly constrained. The common mineral impurities in the active or dead-burnt MgO products, such as lime [CaO], calcite [$CaCO_3$] or dolomite [$CaMg(CO_3)_2$] complicate the process understanding. Using the computer code PHREEQ-C and the carbfix.dat database, which was adapted by reported and experimentally obtained solubility data of various Mg/Ca-organo salts, we have modelled a series of reaction pathways in the CaO-MgO-CO_2-H_2O-organo system. The developed thermodynamic models allow an enhanced understanding of i) the respective stabilities of the relevant binder phases and ii) the organo-complexation behaviour of Mg and Ca as a function of the prevailing pH, acid concentration and Mg/Ca ratio.

A new tool for tungsten exploration – Application of scheelite fingerprinting to assess tungsten mineralization in the Eastern Alps, Austria

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Tungsten is a raw material in demand with great economic and strategic importance for the European industry, but with an increased supply risk. Accordingly, tungsten is listed by the EU Commission as critical raw materials for the EU 2020. To guarantee secure supply for Europe, it is important to explore the national raw material potential more intensively, in order to enhance strategic autonomy. Europe's largest producing tungsten mine is the world-class Felbertal scheelite deposit in Austria. Its discovery in 1967 triggered substantial greenfield exploration during the 1980s and led to the discovery of many non-economic tungsten occurrences in the Eastern Alps. "W Alps" is a joint project between the Geological Survey of Austria, Montanuniversität Leoben and Wolfram Bergbau und Hütten AG. It aims to establish assessment criteria ("fingerprints") for the evaluation of regional tungsten potentials in Austria, which can be used in mineral exploration. So far, our data base includes field-based and analytical data of 17 tungsten occurrences. The mineralogical and chemical signatures of the economically most important Felbertal deposit will be used, together with those from the other scheelite occurrences, as indicative for tungsten endowment. Scheelite ($CaWO_4$) is the most common tungsten mineral in the Eastern Alps occurring in different geological settings and mineralization styles. Scheelite is studied using a combination of cathodoluminescence (CL), electron probe micro analysis (EPMA) and laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) techniques. The quest for "primary" scheelite signatures is complicated by coupled dissolution-reprecipitation and recrystallization processes during hydrothermal formation and especially subsequent regional metamorphism, causing multiple types of scheelite with different trace element composition in most deposits/occurrences. Thus, scheelite types in all occurrences were chronologically sorted by combining CL-textures and distinct trace element patterns (e.g., REE). Trace element distribution of scheelite is mainly controlled by the fluid chemistry and element fractionation between fluid and scheelite and other co-existing phases during crystallization of scheelite. It is also significantly modified during subsequent metamorphic mobilization of pre-existing scheelite. We will point out this temporal evolution of scheelite textures and chemistry and their importance for mineral exploration. Moreover, the combination of geological information and scheelite data aids to reconstruct the ore forming environment and enables the discrimination between magmatic-hydrothermal and metamorphogenic processes. This also allows to revise the current metallogenic model for tungsten mineralization in the Eastern Alps.

Cenozoic mass occurrences of larger benthic Foraminifera in the Mediterranean region: What can we learn from the current range expansion of Amphistegina lobifera?

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There are several records of Cenozoic mass occurrences of Larger Benthic Foraminifera (LBF) from the Mediterranean region. The nearly monospecific Nummulites facies of the Paleocene/Eocene or the Amphistegina-Limestones of the Miocene and Pliocene are generally associated with times of warm ocean temperatures, e.g., the PETM. During the Pleistocene, many taxa of LBF have been very restricted or disappeared entirely from the Mediterranean. However, since the opening of the Suez Canal and the ongoing ocean warming, extensive range expansions of relict and newly introduced LBF and other warmwater-associated foraminifera have been observed. Among those, *Amphistegina lobifera* is the most prominent example and it already exhibits the potential to form mass occurrences again. We have analyzed sediment samples from Corfu Island in the central Mediterranean and compared them with data from Pleistocene deposits from the same area. We found that the fossil assemblages are dominated by small miliolid and epiphytic foraminifera and LBF are virtually absent. However, the arrival of *Amphistegina lobifera* appears to have initiated a faunal turnover represented by a significant decrease in small miliolids and epiphytes in samples where *A. lobifera* is particularly abundant. At the same time, several LBF and other warmwater taxa show increasing abundances. These observations shed light on the structure and time frames of community changes associated with LBF invasions and might serve as modern analogues for the development of mass occurrences in the past.

Mapping active faults in the region of Vienna to minimize seismic risks associated with geothermal energy production

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In the last decades, the increasing need for renewable energies led to an exponential growth of enhanced geothermal projects in many parts of the World, including continental Europe. That led to several episodes of unpredicted induced seismicity, which in some instances resulted in the temporary interruption of the geothermal activities or even to the complete cancelation of projects. Unwanted seismicity can occur as an effect of pore pressure build-up during the injection of cooled water which is associated with the decrease of the effective normal stress acting on faults and therefore can lead to unpredicted fault-slip and triggered seismicity. The recognition and precise mapping of active and critically stressed faults which could be triggered by injection was therefore analysed during the project GeoTief 3D EXPLORE. The project addressed the exploration of hydrothermal resources in Vienna. A substantial effort was made to identify, map, and assess, Quaternary faults to delimit areas where the reinjection of thermal water should be avoided. In the Miocene pull-apart Vienna Basin several small fault-delimited depressions developed during the Quaternary. These basins are delimited by active normal faults branching off the main strike slip fault of the Vienna Basin Transform Fault System. Displacements during the Pleistocene left distinct marks in the late Pleistocene landform configuration of fluvial terraces. Fault scarps and fault-related valleys are clearly cognized in high resolution LiDAR and satellite images. Fault slip rates can be estimated from the thickness of Quaternary fluvial sediments forming growth strata in the fault-delimited basins. Therefore, a first objective was the modelling of the horizon “Base Quaternary” and the calculation of the thickness of Quaternary sediments from literally thousands of shallow drillings in the Vienna Basin. To achieve an accurate active fault map of Vienna and its surrounding, Quaternary sediment data and geomorphological data were supplemented by high-resolution geophysical mapping of near-surface faults (ERT, 2D reflection/refraction seismic) and interpretation of deep 2D/3D reflection seismic. In the geothermal prospection area data highlight two major normal fault systems referred to as the Seyring and Aderklaa faults, each comprising of several fault splays. Paleoseismological evidence proves that both systems were the loci of strong prehistoric earthquakes (Weissl et al., 2017, Quaternary International, 10.1016/j.quaint.2016.11.022; Oppenauer et al., 2022, this volume). The evidence of Quaternary fault slip, the occurrence of strong paleoearthquakes and evidence for critical stressing of at least one of the faults (Levi et al., 2022, this volume) calls for utmost carefulness when selecting sites for the injection of cooled thermal water.

A model to access geochronological data for the Geological Survey of Austria

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Since its beginnings in the 20th century, geochronology provides a unique possibility to give an absolute age to geological features. A wide range of methods allows for temporal constraints on geodynamic processes such as the emplacement of igneous rocks, metamorphic and tectonic events, cooling and exhumation of basement rocks as well as erosion and deposition of sediments. Nowadays, the huge amount of available geochronological data provides a basis for geodynamic models and a modern understanding of the associated geological processes. However, the information is often scattered over several publications, buried in inaccessible articles from historical ("grey") literature or it does not meet modern standards (e.g., ages calculated using outdated decay constants). Thus, the collection and assessment of geochronological data is an essential, but time-consuming and reoccurring task for many geological projects. Additionally, best practice in scientific research calls for a meticulous documentation of new data to allow for the reproducibility of results. To improve the accessibility and documentation of geochronological data at the Geological Survey of Austria, a project was set up to amalgamate geochronological data in a structured database. The data collection covers common dating methods and isotope systems including cosmogenic isotopes. To make them available as a point layer for geographic information systems (GIS), the data model assigns dated minerals from publications as well as the necessary background information of the samples to a geographical located point (GCHRON_number). The storage of the whole dataset allows, as simple as possible, a recalculation of geochronological data. The data model is structured in different data tables, directly linked to a key table including the GCHRON numbers, which is linked to the coordinate and detailed information of the dated mineral, lithology, geological unit and the corresponding geochronological method. Detailed information for each method is provided in separate tables. Several results from single minerals and from different methods can be attributed to one GCHRON number. At this stage, results from the U/Pb, Rb/Sr, Sm/Nd, K/Ar, Ar/Ar, Fisson Track, U-Th/He and Lu/Hf dating of various minerals and whole rock material are included, referring to the method and dated material. Of course, calculated ages are also provided. In addition, a link to the reference, to open access respectively free access publications in the library of the Geological Survey, is provided. At the present stage, data from around 40 publications have been processed, primarily from the area east of the Tauern Window. This data model will facilitate geological work in projects of regional geology by providing a transparent uniform basis of available data. The geochronological data model will be evaluated during its internal use at the Geological Survey prior to its publication.

Investigation of occurrences of high-quality quartz mineral resources in south-eastern Austria: First results from the Rittis quartzite

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In Austria, there is a high demand for high-quality quartz mineral resources, which, depending on the quality, are used in the glass, foundry or construction industries. The demand forecast indicates a continued upward trend for the next few years. Therefore, potential deposits of quartz sand, quartzite, pegmatite quartz and quartz from mobilisate layers are investigated in the frame of the project MRI_QUARTZ, supported by the “Initiative GBA Forschungspartnerschaften Mineralrohstoffe – MRI”. In this contribution, first results from the “Rittiser Quarzit” (Cornelius, 1952) are reported. It forms layers within orthogneiss (“Grobgneiss”) in the surrounding of the village Rittis/Krieglach (Styria). There, in the years 1860 to 1935 quartz of high-purity was mined from 16 sites, both in open pits and underground. In a raw material geological study by Erkan (1982) the quartz layers were interpreted as Permian-Lower Triassic metamorphic quartzite forming xenoliths within the orthogneiss. Geochemical investigations indicate an average purity of ~91 % SiO_2, whereas material from the dumps reached a SiO_2 content of up to 99 %. According to the recent nomenclature of the Geological Survey of Austria the Rittis quartzite appears within the Pretul orthogneiss, which is embedded in phyllonitic mica schists and paragneiss (“Hüllschiefer”). Together they form the Teufelstein Complex building up the Stuhleck-Kirchberg Nappe of the Koralpe-Wölz Nappe System (Austroalpine) (Matura & Schuster, 2014). The Pretul orthogneiss developed from biotite and locally two-mica granite with K-feldspar phenocrysts up to a few centimetres in size. LA-ICP-MS dating on zircons yielded Permian intrusion ages in the range of 250–285 Ma for different bodies of the widespread occurring lithology (Schuster et al., 2010; Yuan et al., 2021). For a sample from quarry Hadersdorf near to Rittis an age of 256 ± 8 Ma was determined. The gneissic texture developed during the Eo-Alpine tectonothermal overprint at greenschist facies conditions. Mapping revealed that the areas designated as Rittis quartzite in the published maps are not homogeneous bodies, but rather represent areas in which more or less pure quartz layers with up to 2 m in thickness occur within the orthogneiss. The latter Eoalpine deformation is expressed by a uniformly 20°–30° WNW dipping schistosity and top NW directed kinematics. The quartz layers are parallel to the schistosity, showing distinct contacts to the orthogneiss. They are homogeneous with no internal zoning or bedding, but single feldspar grains or lenses of orthogneiss may be embedded. Sometimes within the quartz a stretching lineation dipping shallowly (10°–15°) to the SW is developed. Often it is highly fractured or cataclastically deformed and rarely discordant quartz veins up to several centimetres in thickness are present. Due to the field observations, the Rittis quartzite is interpreted as quartz mobilisate layers formed during Eo-Alpine metamorphism. With geochemical and reserve investigations underway, the reserve potential is to be evaluated.

From ice streams to meltwater channels: Detailed study of a vast ancient ice sheet of the LPIA in the Ennedi Plateau, Chad

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The sedimentary record of the Late Paleozoic glaciation is recorded and intensely studied all over Gondwana but understudied in northern Africa. Only two locations, in Niger and Chad, have thus far been found and only the former has been subject to field investigation. Across the Ennedi Massif in northern Chad, Paleozoic rocks are exposed in sandstone plateaux and exhibit a convincing geomorphological record of subglacial activity. Features consistent with ancient ice streams can be traced northwards into the Mourdi depression. Glacial lineations, moraines and exhumed channels in positive relief provide strong evidence for the existence of a vast ice sheet covering large areas of the Ennedi Plateau. Channel structures in positive relief provide insight into meltwater release during different stages of ice sheet development. Various ridges cross-cut one another in a possible proglacial system recording significant meltwater release. In this study, satellite images were manipulated using various techniques to extract lithological differences and mineral composition from the Ennedi Massif. We note (i) considerable mineralogical variation between known palaeo-ice stream and interstream areas across the plateaux which probably proxy lithological differences, (ii) the presence of a newly discovered palaeo-ice stream to the western extremity of the plateau, (iii) provide topographic and geomorphological evidence for a putative grounding zone wedge, supporting the interpretation of a marine terminating Paleozoic ice sheet and (iv) the architecture of braided and meandering channel systems including possible internal channel heterogeneities and point bar configurations. The application of band rationing and image manipulation techniques is the first step in the generation of an initial geological map specifically for the Late Palaeozoic glacial record of Chad, which needs to be ground-truthed in future geological fieldwork. Overall, the glacial record of the Ennedi Plateau throws significant new light on the ‘big picture’ of Paleozoic glaciation and expands the general understanding of deep-time glacial landsystems.

Coal forming environment of low-rank coal seam in Sandaoling mining area, Turpan-Hami Basin

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As an unconventional natural gas, coalbed methane (CBM) has important significance for the sustainable development and transformation of traditional energy sources. Pores and fractures in coal seams are the main storage space for CBM, and the depositional environment controls the development of coal seams and it also has an impact on the adsorption of CBM. Tuha Basin in northwest China has a wide distribution of thick coal seams, which storing abundant low-rank coalbed methane resources. However, the research on coal reservoirs is not enough to support the exploration and development of local resources in this area. The study area of this research is located in the Sandaoling mining area of Tuha Basin, and the target coal seam is the Middle Jurassic Xishangyao group 4# coal. In this research, we measured the microcomponent content, coal quality parameters content and geochemical elements content of nine coal samples, and classified the coal forming environments into two categories: Dry forest swamp and moist herbaceous marsh. (1) The coal forming environment type of the top and bottom coal seams is dry forest swamp. Water recharge in the environment was provided by both atmospheric precipitation and subsurface runoff, and the ash and sulfur content of the water was low. The main plant type in the environment was woody plant. The coal seams formed during this period have a high content of inertinite, and the macrolithotypes are dark and semi-dark coals. (2) Moist herbaceous marsh was the main type of peat swamp in the middle period of coal formation. During this period, the climate was arid and the water level in the marsh was high. Atmospheric precipitation was the main way to provide water to the marsh. The coal forming environment was a reduced environment, and the plant type was mainly herbaceous. The coal samples formed in this coal-forming environment have a high content of vitrinite, and the macrolithotypes are bright and semi-bright coals.

Artifical maturation experiments on Qingshankou Formation shale: Porosity changes and implications for hydrocarbon expulsion behavior

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The Upper Cretaceous lacustrine Qingshankou Formation (Songliao Basin, NE China) is a promising shale oil target due to its remarkable source potential. The formation reaches total organic carbon (TOC) contents > 10 wt.-% and hydrogen index (HI) values of > 700 mg HC/g TOC in its most prolific parts, resulting in a substantial shale oil potential. Previous studies targeted the expulsion behavior of the Qingshankou Formation and reported a maximum of extractable organic matter, pore volume occluded by bitumen, as well as Rock-Eval S1 hydrocarbons and high molecular weight bitumen (solvent-extractable part of the Rock-Eval S2 peak) in place at a vitrinite reflectance (VR) of ~0.8 %Ro. Furthermore, a reportedly sharp decrease in these parameters at > 0.9 %Ro indicates a good expulsion efficiency of the Qingshankou Formation in comparison to other oil-prone source rocks. However, work on natural source rock maturation profiles cannot exclude lithological variations as well as possible uncertainties in maturity determination. Hence, laboratory-based maturation experiments such as hydrous pyrolysis offer a great opportunity to expand the knowledge on the organic matter transformation-related pore space evolution within a potential shale oil reservoir. This contribution presents microstructural data gained from a series of artificially matured Qingshankou Formation shale samples. Hydrous pyrolysis experiments have been conducted on an initially immature sample at 0.55 %Ro with an initial TOC of 11.0 wt.-% and an initial HI of 744 mg HC/g TOC. Six sub-specimens originating from the same sample have been pyrolyzed up to corresponding VR values of 0.8, 1.0, 1.1, 1.2, 1.3, and 1.5 %Ro and investigated via broad ion beam – scanning electron microscopy (BIB-SEM) porosimetry (detectable pore size range from 30 nm to ~2 µm) to capture porosity changes related to i) hydrocarbon generation and resulting pore occlusion, as well as ii) hydrocarbon expulsion and secondary cracking. The change in image-based porosity shows a clear trend of pore occlusion, which results in a drastic decrease of porosity from 8.9 vol.-% at 0.8 %Ro to 0.7, 1.4, and 2.5 vol.-% at 1.0, 1.1, and 1.2 %Ro, respectively. A sharp increase in porosity to 13.6 vol.-% at 1.3 %Ro suggests that the main phase of hydrocarbon expulsion occurs between 1.2 and 1.3 %Ro at the given experimental maturation settings, resulting in a drastically changed microstructure of the rock. This is remarkably late compared to the suggested main expulsion phase around 0.9 %Ro reported for the natural maturity profile. It is yet unclear if this difference is due to a limited comparability of fast artificial laboratory-based and slow natural thermal maturation (despite matching VR), or caused by lithological heterogeneities (e.g., changes in grain size or bulk mineralogy). At the onset of the dry gas window (1.5 %Ro) the image-based porosity of the pyrolyzed sample decreases to 7.2 vol.-%. This may be due to the inherent variability of the hydrous pyrolysis experiment, but may also indicate further occlusion of pores due to ongoing hydrocarbon cracking, or possibly stronger pore pressure-relaxation effects at the main stage of expulsion at 1.3 %Ro. In summary, the results of this study emphasize the dramatic pore space changes during maturation of a highly oil-prone source rock. This has important implications for shale oil extraction behavior, but also for the matrix permeability evolution of organic-rich seal rocks.

The mine drainage from the spoil tip of a Bavarian pitch coal mine – a history of unmonitored natural attenuation

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For more than 60 years, since the abandonment of coal mining in the Hausham colliery, mine drainage from the site percolates an associated spoil tip over a distance of several hundred meters, before discharging into a nearby lake – the Loidlsee. Generally, coal mine drainage is often characterized by poor water quality, e.g. low pH values, high concentrations in dissolved toxic metal ions and high salinity, posing environmental risks for receiving streams. With this in mind, a closer examination of this apparently unmonitored coal mine discharge was carried out in summer 2020. A coupled elemental and isotopic approach was applied to reconstruct the origin and chemical evolution of mine drainage. Water samples were taken along the mine drainage and from surface waters in the close vicinity of the mine drainage. In addition, solid samples from secondary phases along the mine drainage were analysed. At the discharge location the mine water has a pH-value around 6.5, an electrical conductivity of 2,710 µS/cm and high concentrations of sulphate (> 1,000 mg/l) and iron (2,8 mg/l) and elevated contents of nickel. These values are significantly reduced over the course of the mine water flow, providing the water to enter lake Loidlsee environmentally non-hazardous. Decreasing values are linked to (1) the formation of secondary iron precipitates, (2) the formation of secondary calcium carbonates along the mine drainage and (3) mixing with a different groundwater source along the flow path. $^{34}S/^{32}S$ isotopic ratios of dissolved SO_4^{2-} point to the oxidation of sulphidic minerals such as pyrite. δ^2H_{H2O} and $\delta^{18}O_{H2O}$ values of the mine drainage differ significantly from those of the surface waters which is interpreted as evidence for several flow systems with varying retention times in the catchment.

The role of low-field nuclear magnetic resonance in critical zone research

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Many pressing environmental issues, such as the dynamics of surface water and groundwater, the behaviour of the changing cryosphere, addressing soil and water pollution, and the dynamics of natural and intentional carbon storage, are strongly linked to critical zone processes. Understanding the linkage and interactions among geological, hydrological, chemical, biological, climatic, and anthropogenic processes within the critical zone requires innovative scientific approaches. Geophysical methods characterize the spatiotemporal distribution of subsurface properties in a minimally invasive way and have shown great promises in critical zone research. Among these methods, low-field nuclear magnetic resonance (NMR) is an emerging method that has been used in many geoscience and environmental science applications. Leveraging its direct sensitivity to the proton, the low-field NMR provides non-invasive and fast characterization of different natural and engineering systems. In critical zone research, NMR measurements have been performed at the bench scale, borehole scale, and surface and allow prediction of basic properties of rocks and porous media, including volumetric water contents, saturation degrees, porosity, pore-size distribution, the amount of irreducible and free water, permeability, and hydraulic conductivity. In this presentation, I will discuss how water content, water distribution and fluxes, and weathering processes in carbonate critical zones are quantified and predicted using NMR methods at various scales. I will show how to link laboratory NMR findings with field NMR observations in this context. The key hydrogeological parameters will be quantified, the conceptual model of groundwater flow paths will be updated, and the water distribution in unsaturated weathered bedrock in a karst system will be defined using a recent study as an illustration. Through laboratory studies, theoretical modeling, and field work, we develop new NMR methodologies to improve the understanding of critical zone architecture and the hydro-, bio-, and geochemical processes within it.

Fracture compliance estimation in crystalline rock masses from fullwaveform sonic data

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The presence of fractures, which create fluid pathways and zones of weakness in their embedding background rock mass, is ubiquitous throughout the Earth's upper crust. Correspondingly, there is interest not only in the detection, but also, in the quantitative characterization of mechanical and hydraulic fracture properties for a wide range of applications throughout the geo-, environmental and engineering sciences. An important mechanical property is the compliance of fractures, as it quantifies the opening or closing of a fracture in response to pressure changes, which play a role for hydraulic stimulation experiments and induced seismicity. Seismic borehole methods, especially full-waveform sonic (FWS) data, have indicated their potential to infer the compliance of individual macroscopic fractures under in situ conditions. So far this has been achieved for a specific acquisition set-up of static FWS measurements which are characterized by a very high data quality. In this study we evaluate the potential to estimate fracture compliances from standard, production type FWS data in a crystalline rock mass. To test the robustness of fracture compliance estimation from production type data with respect to the data quality and other factors of influence e.g., heterogeneity of the background rock mass we perform a set of numerical simulations. The impact of different signal-to-noise ratios, i.e. data quality, on fracture compliance estimates is then evaluated by contaminating the synthetic FWS data sets with scaled noise traces extracted from standard, production-type field data. These FWS field data sets were acquired before and after a mini-frac hydraulic stimulation campaign in a granitic rock mass. In a next step we estimate from the field data compliances of natural and small man-mad fractures created by the stimulation. The estimates are sufficiently robust for the natural fractures, and are still feasible for generally much smaller man-made fractures. This in turn may shed some light on the differences between these two fracture types.

High-resolution spatiotemporal pH monitoring of coupled CO_2 degassing and $CaCO_3$ precipitation dynamics

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In situ monitoring of chemical and physical parameters of drip sites in caves (or groundwater seepage in tunnels) allows for an advanced understanding on the controls of carbonate precipitation dynamics. The pH can be used as key parameter to trace varying CO_2 degassing and saturation states with respect to $CaCO_3$ in aqueous media. Due to rapid CO_2 degassing of drip water reaching the cave or tunnel atmosphere, and slow drip rates, pH measurements using conventional (electrode based) methods, can be altered towards higher pH within seconds. Thus, a precise and immediate pH measurement is crucial to determine the prevailing $CaCO_3$-CO_2-H_2O processes, i.e. reaction kinetics, isotope fractionation, and the occurrence of intermediate carbonate phases. Furthermore, it may allow to distinguish between site-specific and more general climate related signals. In the present study novel optical pH sensors with an integrated sensing layer containing pH sensitive dyes are applied in order to quantify and visualize spatial pH distributions of simulated and real-life drip water forming speleothems with high-temporal and spatial resolution. Preliminary results in flow path simulating laboratory experiments that use multiple pH sensors show a standard deviation of only ± 0.1–0.01 for pH and a good reproducibility of the measurements under restrictive conditions with a water film thickness of < 1 mm and slow flow rates of ~1.5 cm/s. As the pH sensors are suitable for even thinner water films of ~0.1 mm, their applicability was tested in Katerloch Cave, producing pH profiles along the flow path of an active stalagmite. The data of the pH sensors reflect the prevailing CO_2 degassing dynamics, which was also supported by hydrochemical analysis using spatiotemporally resolved fluid sampling with glass capillaries containing volumes between 100 to 200 µl.

Die Sideritlagerstätte des Steirischen Erzberges

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Zusammenfassung

Der Steirische Erzberg ist seit Jahrhunderten das Bergbauzentrum in der Obersteiermark. Die Erzproduktion von jährlich über 3 Millionen Tonnen Versanderz an die Stahlwerke in Donawitz und Linz sichert Arbeitsplätze und Wohlstand in der Region. Während der Exkursion werden die Bergbaugeschichte und die Erforschungsgeschichte des Erzberges erläutert sowie interessante geologische Aufschlüsse im aktiven Tagebau besucht. Die wichtigsten am Erzberg auftretenden Gesteins- und Erztypen werden vorgestellt und in die genetischen Konzepte einbezogen. Zum Abschluss wird mit dem ZaB („Zentrum am Berg“) ein weltweit einzigartiges Tunnelforschungszentrum vorgestellt.

Abstract

The Styrian Erzberg has been the mining centre in Upper Styria for centuries. The ore production of over 3 million tons of ore annually shipped to the steelworks in Donawitz and Linz secures jobs and prosperity in the region. During the excursion, the mining and exploration history of the Erzberg will be explained and interesting geological outcrops in the active open pit mine will be visited. The most important rock and ore types occurring at Erzberg will be presented and included in the genetic concepts. Finally, the ZaB (“Zentrum am Berg”), a unique tunnel research centre worldwide, is presented.

1. Geschichte

Seit mehr als 1.300 Jahren gilt der Steirische Erzberg als der „Steirische Brotlaib“. Der Beginn des Eisenerzabbaus in der Region Eisenerz ist nicht gesichert, er dürfte möglicherweise bereits auf das 3. nachchristliche Jahrhundert zurückgehen. Das Jahr 712 gilt als Gründungsdatum des Eisenbergwerks (HASITSCHKA, 2012). Zu Beginn wurde das gewonnene Erz nahe der Gewinnungsstätte in Rennöfen verhüttet, vermutlich direkt am Präbichl; in unmittelbarer Umgebung dürften sich auch die ersten Schmieden befunden haben. Bereits im 13. Jahrhundert wurde das Erzvorkommen in das südlich gelegene Vordernberger Revier sowie das auf die heutige Stadt Eisenerz zugewandte Innerberger Revier unterteilt, wobei die sogenannte Ebenhöhe (Seehöhe 1.186 m) als Grenze galt. Beide Reviere waren in einzelne Gruben aufgeteilt, deren Besitzer sowohl den Abbau als auch den Transport zu den Verhüttungsanlagen individuell organisierten. Im 14. Jahrhundert wurde durch Verfügung der Landesfürsten der Abbau des Eisenerzes am Steirischen Erzberg, die Erzeugung des Roheisens sowie die Weiterverarbeitung geordnet. Die Eisenordnungen von 1448 bzw. 1453 regelten auch die Absatzgebiete: Das Revier Innerberg belieferte Nordeuropa, das Revier Vordernberg hingegen Süd- und Südosteuropa; diese Aufteilung war durch die Wasserwege für den Abtransport des gewonnenen Eisens vorgegeben. Um die Produktionszahlen steigern zu können, benötigte man leistungsstärkere, größere Öfen. Man bediente sich Wasserrädern, bei denen das Gebläse für Verbrennungsluft durch ein Wasserrad betrieben wurde. Die Verhüttungsanlage erhielt folglich die Bezeichnung Radwerk und sein Besitzer war der Radmeister. Vordernberg hatte 14 Radwerke; ihre Nummerierung erfolgte kontinuierlich von Norden nach Süden dem Bachlauf folgend. In Innerberg arbeiteten bis zu 19 Radwerke. Zu einem Radwerk gehörte nicht nur der Schmelzofen selbst, sondern insbesondere auch ein Anteil am Bergbau, Waldungen für die Holzkohlenproduktion, Schmelzhalle, sowie Erz- und Kohlelager (SCHÖPFER, 2012; EFFENBERGER & MELCHER, 2017).

Das geförderte Erz wurde zuerst nach Grob- und Feinerz getrennt, dann zwecks Dekarbonatisierung geröstet. Das Feinerz musste gesondert mit Kohle vermengt gesintert werden, um ein Verkleben im Röstofen zu vermeiden. Die Weiterverarbeitung erfolgt im Ennstal, Ybbs-, Erlauf-, bzw. Mur- und Mürztal; hier konnte nicht nur die Wasserkraft genutzt werden, es standen auch ausgedehnte Wälder für die Holzkohlenproduktion zur Verfügung.

Im 16. Jahrhundert erfolgte der Übergang zum Grubenbau. Ab 1625 wurden die nördlich des Präbichls gelegenen Radwerke mit den zugehörigen Grubenanteilen sowie die Weiterverarbeitung des Roheisens und der Eisenhandel in der Innerberger Hauptgewerkschaft zusammengefasst. Es wurde ein landesfürstlicher Oberaufseher über das gesamte Eisenwesen, der Kammergraf, ernannt. Als Amtssitz dieses Beamten wurde der Eisenerzer Kammerhof errichtet. Die Radmeister und die Eisenverleger des südlichen Reviers blieben vorerst weiterhin selbständig. Ab 1760 wurden die Stucköfen durch die sogenannten Floßöfen ersetzt. Wie bei modernen Hochöfen wurden diese von oben beschickt und das flüssige Roheisen wurde im unteren Bereich regelmäßig abgestochen. Der kontinuierliche Betrieb des Ofens senkte den durch das Wiedererhitzen hohen Energiebedarf; dadurch konnte der Verbrauch an Holzkohle um fast 50 % gesenkt werden. Später wurde auch noch die zugeführte Luft vor dem Einblasen erhitzt bzw. die warmen Abgase wiederverwendet (SCHÖPFER, 2012). Ursprünglich erfolgte der Abbau am Steirischen Erzberg hauptsächlich unter Tage. Erst um 1870 setzte sich der Tagebau langsam durch und wurde ab 1986 ausschließlich betrieben.

Zu Beginn des 19. Jahrhunderts kam es zu einer schweren Krise der Vordernberger Eisenindustrie. Sowohl im Gruben- als auch im Tagebau war eine Sanierung durch Reorganisation dringend nötig. Erzherzog Johann, der seit 1823 ein Radwerk in Vordernberg besaß, setzte 1829 bei den übrigen Radmeistern die Neugründung der Vordernberger Radmeisterkommunität durch. Sowohl der Erzabbau als auch die Erzförderung auf dem Steirischen Erzberg wurden reorganisiert und modernisiert. Die Erzrechte gingen in ein gemeinsames Eigentum über; der Abbau sowie der Transport des gewonnenen Erzes vom Erzberg zu den Radwerken in Vordernberg wurden fortan gemeinsam betrieben. Die Kosten für die Vordernberger Hochöfen konnten durch die Vereinigung der Gruben und den Bau einer gemeinsamen Förderanlage um knapp 40 % verringert werden. Zur Erleichterung des Erztransportes wurde die „Dullnigsche Erzförderbahn“ errichtet, die von 1844 bis 1847 zwischen dem Präbichl und Vordernberg gebaut wurde. Die Erzförderbahn war eine komplexe Konstruktion und bestand aus Horizontaltrassen, Schrägaufzügen und Erzbunkern; letztere stellte die Erzversorgung für die Verhüttung im Winter sicher. Zwischen 1889 bis 1891 erfolgte der Bau der als Zahnradbahn konzipierten Strecke von Vordernberg nach Eisenerz über den Präbichl. Die zu Beginn verwendeten Zahnraddampflokomotiven wurden ab 1962 durch Zahnraddiesellokomotiven ersetzt. 1980 wurden sämtliche Zahnstangen auf der Strecke entfernt, wodurch jedweder Betrieb der Erzbergbahn mit Dampflokomotiven unmöglich wurde. Eine Zahnradbahnlokomotive steht zur Erinnerung an die damalige Erzbergbahn am Vordernberger Marktplatz. Seit 1988 wurde mit einigen Unterbrechungen die historische Eisenbahnstrecke als Museumsbahn geführt (EFFENBERGER & MELCHER, 2017).

Erst zu Beginn des 20. Jahrhunderts entwickelte sich der Bergbau zum Großbetrieb durch Zusammenschluss der innerösterreichischen Eisenwerke zur 1881 gegründeten Österreichisch Alpine-Montangesellschaft ÖAMG (UMFER, 2012). Es wurden Jahresfördermengen von bis zu 2,8 Millionen Tonnen Erz in den Jahren des Zweiten Weltkriegs erreicht. 1973 wurde der Erzberg mit den Hütten der VÖEST in Linz und Donawitz zur VOEST-ALPINE fusioniert. Im Jahr 1989 wurde der Erzberg aus dem VÖEST-Konzern ausgegliedert und der ÖIAG-Bergbauholding Eigentümervertretung unterstellt. Schließlich wurde im Jahr 2004 die Erzberg Privatstiftung Eigentümerin der VA Erzberg GmbH. Das Land Steiermark übernimmt die Position des Letztbegünstigten der Erzberg Privatstiftung.

Derzeit hat die VA Erzberg etwa 230 Mitarbeiter, die jährlich etwa 12 Millionen Tonnen Verhaumenge und 3 Millionen Tonnen Versanderz produzieren. Dies entspricht einer Produktion von knapp 1.000.000 Tonnen Eisen, die durch die VOEST in den Hüttenwerken Linz und Donawitz zu Stählen weiterverarbeitet werden. Seit 1984 beläuft sich die Produktion aus Erzbergerz auf knapp 27 Millionen Tonnen Eisen (Abb. 1); die gesamte bisherige Eisenerzförderung dürfte 250 Millionen Tonnen betragen. Die ursprüngliche Ressource umfasste wahrscheinlich 400–500 Millionen Tonnen Eisenerz.

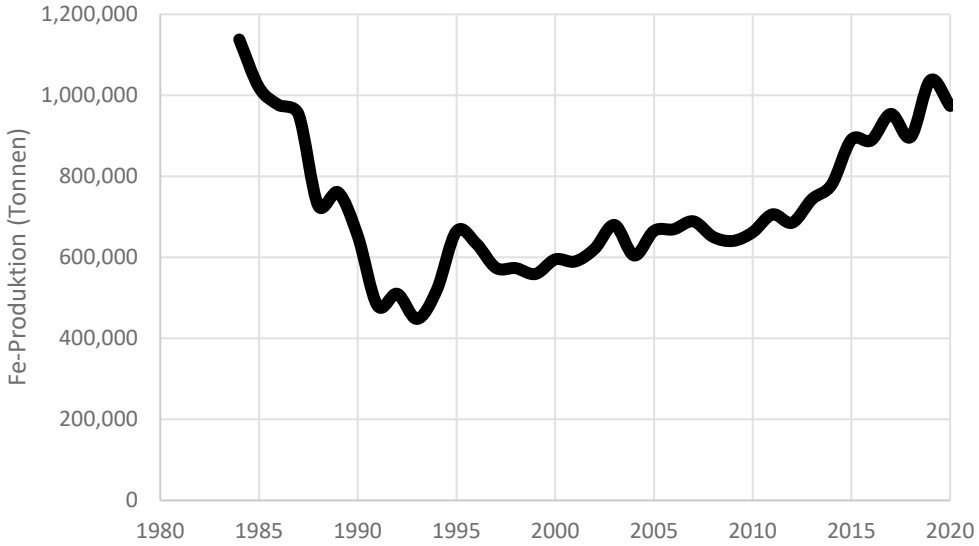

Abb. 1. Eisenproduktion aus Sideriterz vom Steirischen Erzberg seit 1984 (Kompilation aus den Weltbergbaudaten des BMLRT; www.world-mining-data.info).

2. Geologie

Der Steirische Erzberg liegt in der Norischen Decke des Tirolisch-Norischen Deckensystems, einem Teil der historisch als „Grauwackenzone“ bezeichneten Landschaft zwischen Nördlichen Kalkalpen und den Zentralalpen. Die Norische Decke besteht hauptsächlich aus paläozoischen (Ordovizium bis Karbon) phyllitischen Schiefern, metamorphen Vulkaniten (Porphyroide), Kalksteinen (Marmoren), Grauwacken sowie Quarziten (Abb. 2). Besonderes Merkmal der Grauwackenzone ist ein auffallend häufiges Auftreten von Eisen-, Kupfer-, Magnesit-, Talk- und Graphitvorkommen bzw. -lagerstätten, die in den letzten Jahrhunderten zeitweise abgebaut oder beschürft wurden. Im Bereich zwischen Eisenerz und Leoben weitet sich die Grauwackenzone auf rund 25 km; am Nordrand findet sich der Steirische Erzberg, der mit einer Jahresproduktion (2020) von 3 Millionen Tonnen Versanderz das weltweit größte im Abbau befindliche Sideritvorkommen darstellt und nach Kiruna in Schweden der zweitgrößte Eisenerzproduzent der Europäischen Union ist.

Das Liegende der Lagerstätte bilden oberordovizische Porphyroide (Blasseneckporphyroid), die im Bereich der Lagerstätte eine Mächtigkeit von bis zu 400 m erreichen (Abb. 2, 3). Unter dem Porphyroid lagert, an der Präbichlnordrampe aufgeschlossen, die einige 100 m mächtige metapelitisch-psammitische Abfolge der Gerichtsgraben-Formation. Über dem Porphyroid folgen Quarzite, Serizitquarzite, Grauwackenschiefer, graphitische Kieselschiefer (Silur), devonische Kalkschiefer und Marmore („Sauberg Kalke“), letztere mit einer Mächtigkeit bis zu 280 m, sowie die karbonischen Eisenerzer Schichten, die im Bereich der Lagerstätte als grauschwarze phyllonitische Schiefer mit maximal 150 m Mächtigkeit ausgebildet sind und auch als „Zwischenschiefer“ bezeichnet werden. Dieser Zwischenschiefer fungierte als Überschiebungsbahn während der variszischen Orogenese und unterteilt den Erz führenden Bereich in eine Hangendscholle sowie eine Liegendscholle. Die Vererzung liegt lagen- bis linsen- und stockförmig vor; charakteristisch ist eine intensive Verwachsung von Siderit und Ankerit. Der damit verbundene wechselnde Fe-Gehalt ist eine Herausforderung in der Logistik des Abbaus, da für die Verhüttung eine nur wenig schwankende Zusammensetzung gefordert ist. Dies gilt nicht nur für den Fe-Gehalt der Erze selbst, sondern insbesondere auch für weitere Elemente wie Mangan, Schwefel, Phosphor oder Quecksilber.

Die kalkigen Ablagerungen enden an der Wende Unterkarbon zu Oberkarbon, es folgen die Brekzien und Konglomerate der Präbichl-Formation sowie die Werfener Schichten des Oberen Perm und der Untertrias. Diese stellen das Hangende des Erzkörpers dar und bilden andererseits die Basis der Nördlichen Kalkalpen. Die klastische Sedimentabfolge beginnt meistens mit einer bis etwa 40 m mächtigen Basisbrekzie (Präbichlbrekzie), überlagert durch grünliche oder violette, glimmerreiche Sandsteine und Schiefer mit lokalen Einschaltungen von Gips.

Im Bereich der Lagerstätte Erzberg sind sowohl eine variszische als auch eine oberkretazische, eoalpidische Orogenese nachgewiesen. Erstere bedingte die Überschiebung zweier ursprünglich nebeneinander liegender Karbonatschollen (Abb. 3). Graphitreiche Schiefer fungierten als Gleitbahn zwischen Liegend- und Hangendscholle. Zweitere war für die muldenartige Verformung der Lagerstätte verantwortlich. Die größte Störung ist der Christof Hauptverwurf (Abb. 3, 4). Basierend auf Ramanspektroskopischen Untersuchungen an graphitischer Substanz in verschiedenen vererzten und unvererzten Gesteinen wurden im Gebiet des Erzbergs Temperaturen von 300 °C während der alpidischen Metamorphose erreicht (FRÜHAUF, 2017).

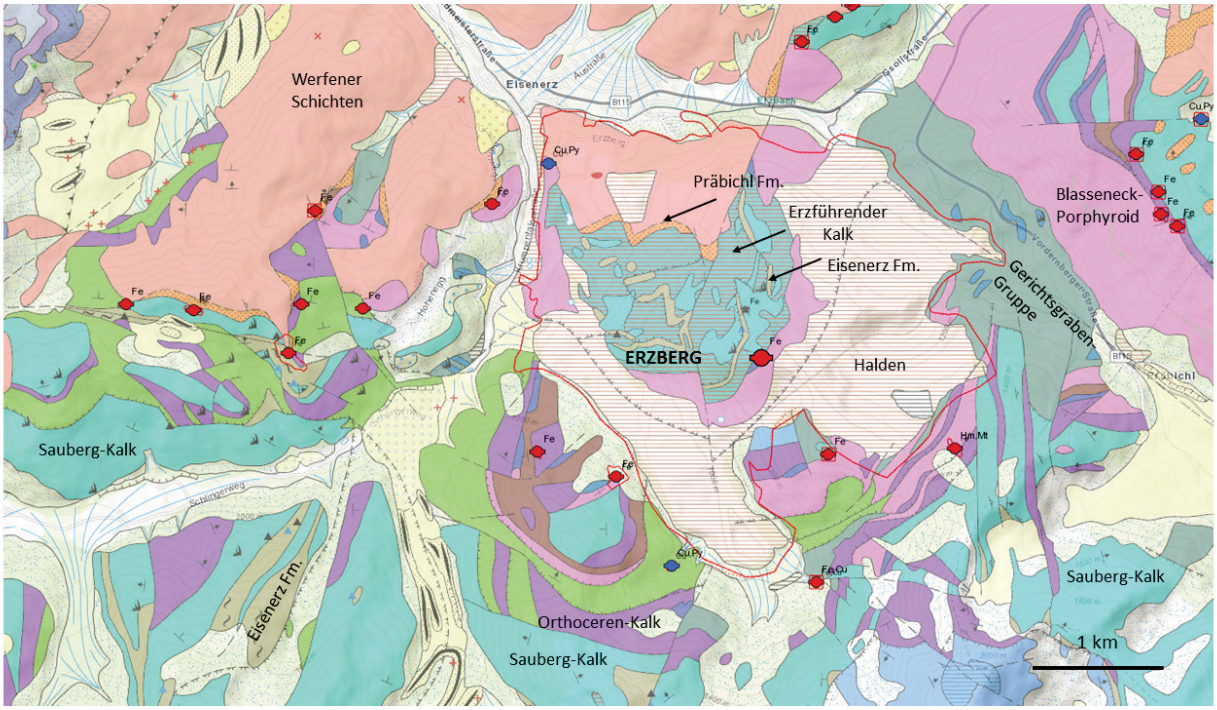

Abb. 2. Geologische Karte des Erzberggebiets mit Symbolen für Rohstoffvorkommen aus dem Interaktiven Rohstoffinformationssystem der Geologischen Bundesanstalt (https://iris.geologie.ac.at).

3. Mineralogie

Die Mineralparagenese des Erzes umfasst hauptsächlich Siderit [$FeCO_3$] und Ankerit [$CaFe(CO_3)_2$, als „*Rohwand*“ bezeichnet], neben Fe-haltigem Dolomit [$(CaMg(CO_3)_2$], Magnesit [$MgCO_3$], und Calcit [$CaCO_3$]. Der Siderit (stöchiometrisch 48,2 Gew-% Fe) ist ein Mg-reicher Mischkristall aus der trigonal kristallisierenden Calcitgruppe. Er wird oft auch unter der von der International Mineralogical Association als „obsolet“ geführten Bezeichnung „Sideroplesit“ geführt. Am Erzberg sind Zusammensetzungen mit ca. 42 % Fe, entsprechend 80–85 Mol-% $FeCO_3$, 5–15 % $MgCO_3$ und 3–7 Mol-% $MnCO_3$ Komponente typisch (BERAN, 1975). Ankerite im Lagerstättenbereich enthalten durchschnittlich etwa 70 Mol-% $CaFe(CO_3)_2$ neben geringeren (2–3 Gew-%) Anteilen an $MnCO_3$. BERAN (1979) konnte texturell und chemisch drei Ankeritgenerationen unterscheiden, die sich bei Temperaturen von etwa 400 °C unter Drucken von 2–3 kbar bildeten. Diese Unterscheidung wird durch Sr-Isotopenuntersuchungen unterstützt (FRIMMEL, 1988).

Untergeordnet sind in Erz und Rohwand Pyrit [FeS_2], Hämatit [Fe_2O_3], Magnetit [Fe_3O_4], Fe-Hydroxide, sowie Quarz, Serizit, Muskovit, Chlorit, Rutil, Turmalin, Zirkon, Apatit, Baryt, Semigraphit und verschiedene Sulfidminerale in unterschiedlichen, stark wechselnden Anteilen vertreten (SCHULZ et al., 1997).

Im Zuge der Erzaufbereitung muss durch Aufkonzentration der Siderite ein Zielwert von 33 % Fe erreicht werden. Bei der Produktion am Berg wird zwischen Reicherz (> 30 % Fe), Armerz (22–30 % Fe) und Baggerbergen (< 22 % Fe) unterschieden; letztere werden verstürzt, Armerze werden aufbereitet, während die Reicherze nach dem Waschen direkt als Produkt ausgeschleust werden können.

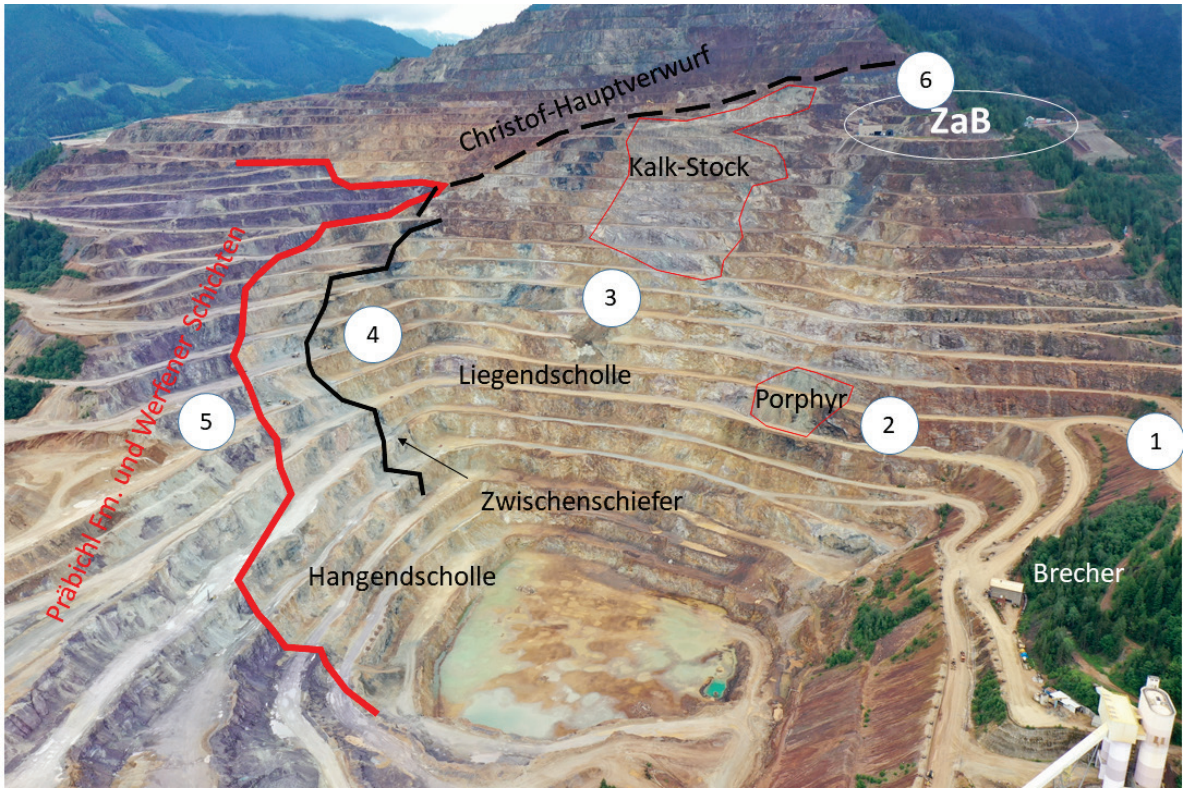

Abb. 3. Luftbild vom derzeit aktiven Bereich des Erzberges mit Exkursionsstops.

4. Exkursionsstops

Stop 1. Bohrerschmiede

Vom Bereich der Bohrerschmiede bietet sich ein hervorragender Blick in den aktiven Tagbau. Anhand des historischen Seigerschnitts (Abb. 4) kann man sich vom Abbaufortschritt überzeugen. Besonders eindrucksvoll sind die tektonisch stark gestörte Überschiebungsbahn mit den dunklen Eisenerzer Schichten sowie der Hangendkontakt zu den Werfener Schichten.

Stop 2. Blasseneckporphyroid und Silurschiefer

Der mittelkörnige oberordovizische Porphyroid ist stark vergrünt und von grobkörnigen Karbonatgängchen durchzogen. Das Gestein besteht im Wesentlichen aus Quarz in Form von Porphyrquarzen, Chlorit, Serizit und Karbonat. Als Karbonate treten Ankerit, Dolomit und Siderit als dünner Saum in den Gängchen gemeinsam mit Fe-Chlorit und Pyrit auf. Im Aufschluss wird der Porphyroid an einer tektonischen Grenze von schwarzen, graphitreichen Schiefern aus dem Silur überlagert.

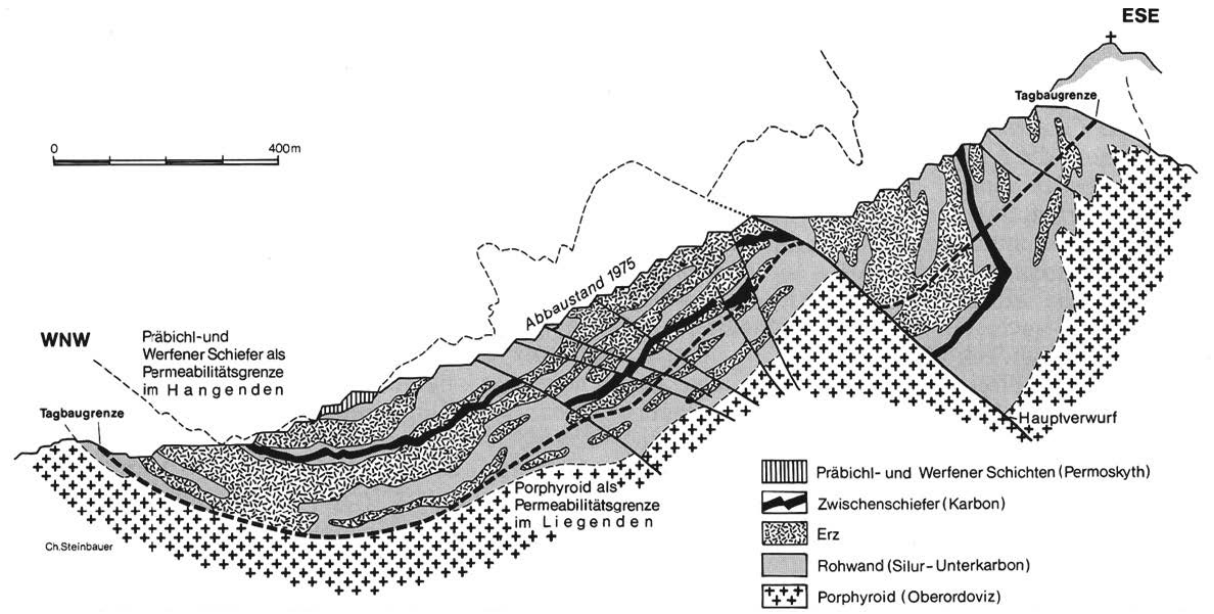

Abb. 4. Seigerschnitt durch den Erzberg, mit historischem Abbaustand von 1975 (HOLZER, 1980). Der durch den „Zwischenschiefer“ (Eisenerzer Schichten, Karbon) markierte variszische Deckenbau wird durch die Präbichl-Formation und Werfener Schichten plombiert. Der (Christof) Hauptverwurf ist eine alpidische Struktur. Erzkörper (gepunktet) durchziehen stock- und lagerförmig den „Erzführenden Kalk“.

Stop 3. Erzkalk und Sauberg-Kalk

Im Bereich der Liegendscholle können im aktiven Bergbaubereich die Beziehungen zwischen Sideriterz und unvererztem Kalk studiert werden. Die Kontakte sind meist diskordant und abrupt. Das Sideriterz ist vielfach als dichter, mittel- bis grobkörniger Sideritmarmor ausgebildet, in dem teilweise Ankeritgängchen und Konkretionen auftreten. Eine schwache Sulfidmineralisation mit vorwiegend Pyrit, Zinnober, in Ausnahmefällen aber auch Chalkopyrit, Fahlerzen und Ni-Mineralen (LIBOWITZKY et al., 2018) ist lokal entwickelt. Der angrenzende, und von Siderit verdrängte Sauberg-Kalk zeigt charakteristische hellrosa gefleckte Kalksteine und Marmore, die im Lagerstättenbereich häufig durch Muskovit und Chlorit leicht vergrünt erscheinen. Die Hauptmasse besteht aus Fe-armem Calcit, der von Stylolithen und Scherbändern durchzogen ist, welche Muskovit, Phengit, Apatit, Quarz, Turmalin, Monazit und Baryt führen.

Stop 4. Eisenerzer Schichten

Im Bereich der Deckengrenze zwischen Liegend- und Hangendscholle sind die graphitreichen Eisenerzer Schichten als hellgraue bis schwarze gebänderte Gesteine mit Siderit, Ankerit, Graphit, Quarz und Serizit entwickelt; sie werden auch als „Tigererze“ bezeichnet. Durch ramanspektroskopische Untersuchungen an Graphiten wurden Temperaturen von 280 °C ermittelt, die durch die regionale oberkretazische Metamorphose erklärt werden können (FRÜHAUF, 2017).

Stop 5. Präbichl Formation und Werfener Schichten

Vererzte Kalke der Hangendscholle sowie stellenweise „Rohwand“ (Ankeritgesteine) werden diskordant, häufig aber mit tektonisch stark überprägten Kontakten, von grobkörnigen Brekzien und Konglomeraten der Präbichl-Formation überlagert. Diese Gesteine sind lokal extrem duktil deformiert. Sie bestehen aus Karbonatgeröllen unterschiedlicher Korngrößen und Farben in einer feinkörnigen tonigen Matrix. Teilweise sind die Komponenten zu Ankerit und Siderit umgewandelt, während die Matrix durch Chlorit vergrünt erscheint. Neben dieser in-toto Vererzung der Präbichl-Formation sind gelegentlich auch stockförmige Bereiche aufgeschlossen, in denen Vererzungsfronten quer durch einzelne Karbonatkomponenten greifen (Abb. 5, 6). SPINDLER (1991) interpretiert die Vererzung der Basisbrekzie als alpidisch bei etwa 200 °C durch Mobilisation aus einem bestehenden Erzkörper entstanden.

Abb. 5. Stark deformierte unvererzte Präbichlbrekzie wird durch eine metasomatische Front von rechts her umgewandelt (Foto: F. MELCHER).

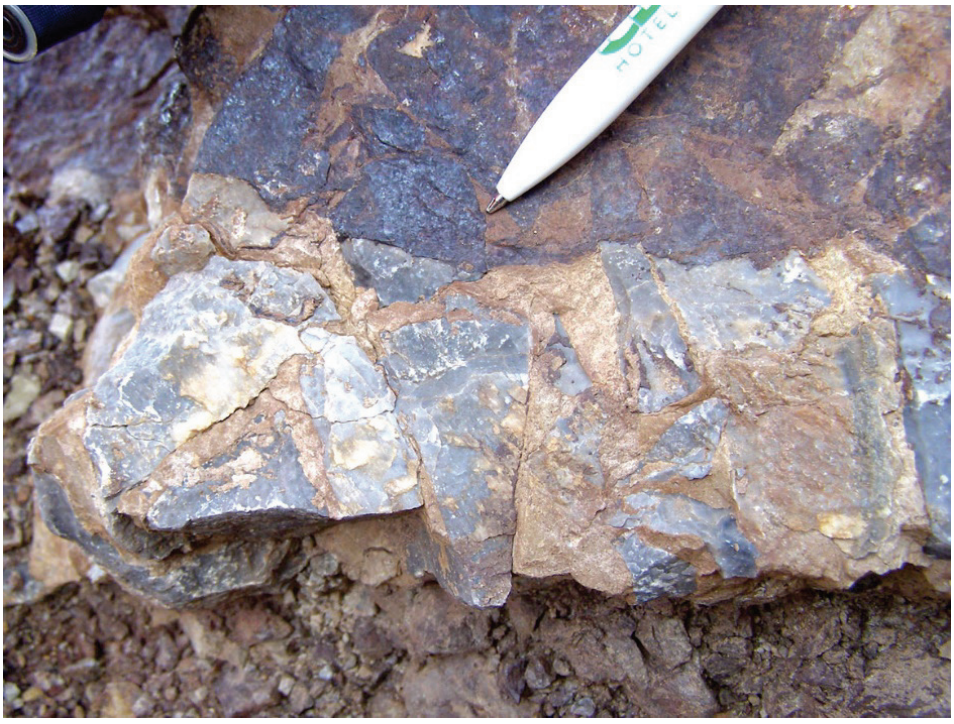

Abb. 6. Präbichlbrekzie, teilweise zu Siderit umgewandelt; Etage Vorauer. Die metasomatische Front verläuft mitten durch einzelne Karbonatkomponenten (Foto: W. PROCHASKA; STROHMAIER, 2009).

Die Präbichl-Formation wird von rötlich-violetten feinklastischen Sedimenten der Werfener Schichten überlagert, die im Lagerstättenbereich keine Spuren einer Siderit-Ankeritvererzung zeigen. Am Nordrand des Tagebaues können Gipseinschaltungen innerhalb der Werfener Schichten beobachtet werden.

Stop 6. Etagen Dreikönig (1.088 m) und Schuchart (1.111 m): Altbergbau, Erzbergit und ZaB

Stop 6.1.

Im Bereich des Straßentunnelportals des ZaB sind sowohl stockförmige als auch gangförmige („Lagergänge“) Siderit-Ankeritgesteine aufgeschlossen (Abb. 7). Es können sowohl abrupte Erz-Nebengesteinskontakte (Abb. 8) als auch eher fließende Übergänge beobachtet werden. Bedingt durch den bereits lange zurückliegenden Bergbau in diesem Bereich sind Erze und Nebengesteine vielfach stark oxidiert. An gesägten Proben und Dünnschliffen können hier vielfältige und komplexe Beziehungen zwischen Nebengestein (Sauberg-Kalk) und dem Siderit-Ankeriterz studiert werden. Es werden mehrere Karbonatgenerationen unterschieden, die sich teilweise in ihrer Mineralchemie deutlich unterscheiden. In Abbildung 9 wird ein Paragenesesschema für die Karbonat- und Sulfidphasen mit dem Versuch einer zeitlichen Einordnung präsentiert (STROHMAIER, 2009; PAMSL, 2016).

Abb. 7. Etage Dreikönig, historisches Foto vor dem Bau des ZaB. Stockförmige störungsgebundene Siderit-Ankeritvererzung im rechten Bildteil, schichtungs-/schieferungsparallele Erzkörper (Lagergänge) im linken Bildteil im nicht-vererzten Sauberg-Kalk (Foto: W. PROCHASKA).

Abb. 8. Kontakte zwischen Siderit-Ankerit-Lagergang und Sauberg-Kalk, Etage Schuchart. Mächtigkeit des Lagergangs: 20 cm (Foto: F. MELCHER).

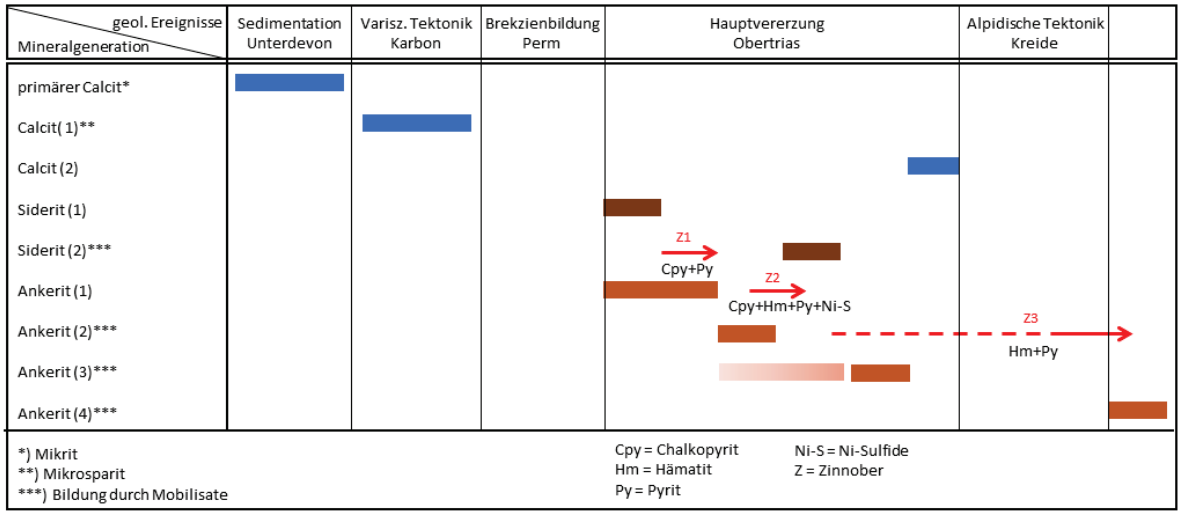

Abb. 9. Relative zeitliche Einordnung der Karbonat- und Sulfidgenerationen am Erzberg, modifiziert nach STROHMAIER (2009) und PAMSL (2016).

Stop 6.2.

Der Erzkalk ist vor allem in den höheren, heute unzugänglichen Bereichen von vertikalen Klüften durchzogen, in denen die als Erzbergit bekannten laminierten Aragonit-Calcit-Sintergesteine auftreten (Abb. 10). Solche Gänge weisen Zentimeter- bis Dezimeterweiten auf und können über Zehnermeter zur Teufe und im Streichen verfolgt werden. Sie werden entweder auf junge tektonische oder auf Massenbewegungen zurückgeführt. Neuere Untersuchungen zeigen, dass die Präzipitate sich durch Infiltration von meteorischen Wässern, Sulfidoxidation und nachfolgende Lösung der Nebengesteinskarbonate ableiten lassen (BOCH et al., 2019). Untersuchungen mittels „clumped isotopes“ ergaben kühle Wassertemperaturen von 0 bis 10 °C, entsprechend der alpinen Umgebung.

Altersdatierungen mittels ^{238}U-^{234}U-^{230}Th reichen von 285.000 ± 3.900 bis 1.030 ± 40 Jahren BP und belegen, dass die Bildung der Erzbergite im Pleistozän und Holozän, vorzugsweise nach dem letzten glazialen Maximum stattfand. Der in brekziierten Lagen mit Erzbergit assoziierte Dolomit auf Etage Schuchart wurde zwischen 19.210 ± 100 und 13.970 ± 80 Jahren BP über ein Mg-Calcit-Vorläuferstadium aus CO_2-entgasten Mg-reichen Lösungen gefällt (BALDERMANN et al., 2020). Die millimeterskalige Lamination der Erzbergite wird als Wachstumsgefüge interpretiert, während ein Lagenbau im Zentimeterbereich auf diagenetische Prozesse zurückgeführt wird. Oftmals sind Erzbergite auch mit den bekannten Eisenblüten assoziiert, so dass ein ähnlicher Bildungsmechanismus angenommen werden kann. BOCH et al. (2019) weisen auf das große Potenzial der Erzbergite zur Klärung paläoklimatischer und Paläoumweltbedingungen hin.

Abb. 10. Erzbergit-Mineralisation in Fe-führendem Sauberg-Kalk, Etage Schuchart (Foto: F. MELCHER).

Stop 6.3. Zentrum am Berg: eine Forschungs- und Entwicklungs- sowie Trainings- und Ausbildungsanlage für sämtliche Berufe im Fachbereich Geotechnik und Infrastrukturbau Untertage.

Mit dem „Zentrum am Berg“ auf Etage Dreikönig verfügt die Montanuniversität Leoben über ein weiteres Alleinstellungsmerkmal in der europäischen Universitätslandschaft. Dieses Zentrum ermöglicht Forschung auf höchstem Niveau in Bezug auf alle Problemstellungen den Tunnelbau betreffend, wie beispielsweise die Weiterentwicklung bestehender und Generierung neuer Vortriebstechniken. Es ermöglicht den Einsatz und die Erprobung neuer Materialien und Ausstattungsvarianten sowie die Anwendung alternativer Tunnellüftungssysteme. Auch für die gesamte Sicherheitstechnik inklusive der im Tunnel integrierten Löschsysteme ergeben sich völlig neue Perspektiven. Die Montanuniversität setzt damit auch einen nachhaltigen regionalpolitischen Impuls für den Großraum Obersteiermark und vor allem die Region rund um Eisenerz. Gedankt sei in diesem Zusammenhang vor allem den Fördergebern von Bund (BMBWF und BMK) und Land Steiermark, welche die Errichtung dieser einzigartigen Forschungsinfrastruktur erst ermöglicht haben. Das „ZaB – Zentrum am Berg”, ist eine Untertageanlage für Forschungs-, Entwicklungs-, Ausbildungs- und Trainingszwecke, die einerseits die Anforderungen der öffentlichen Institutionen erfüllen soll, aber gleichzeitig eine Weiterentwicklungsfabrik für die

zuständigen Universitäten und privaten Unternehmen darstellt. Die Untertageanlage besteht aus zwei parallel geführten Straßentunneln und zwei parallel geführten Eisenbahntunneln, sowie einem Versuchsstollen (Abb. 11), wodurch Forschung, Entwicklung, Ausbildung und Training unter realen Untertagebedingungen im 1:1 Maßstab ermöglicht werden. Die Eisenbahntunnel wurden im Wesentlichen im stark gestörten Porphyroid vorgetrieben, während die Straßentunnel Sauberger Kalk und etwa ab Tunnelmeter 250 eine stockförmige Ankerit-Sideritvererzung durchörterten. Am Tunnelende im „Herzen“ des ZaB treten stark tektonisierte Eisenerzer Schichten auf.

In der Anlage werden aktuell nationale und internationale Forschungsprojekte zu vielfältigen Fragestellungen entlang des gesamten Lebenszyklus von Untertageanlagen durchgeführt. Thematisch werden folgende Themenbereiche angesprochen:

- Geotechnisches Monitoring
- Numerische Simulation in der Geotechnik
- Sicherheitsforschung und Rettungsbedingungen
- Aerodynamische Fragestellungen
- Langzeitstabilität und Dauerhaftigkeit von Materialien
- Sanierung von Untertagebauwerken
- Ausrüstungstechnik

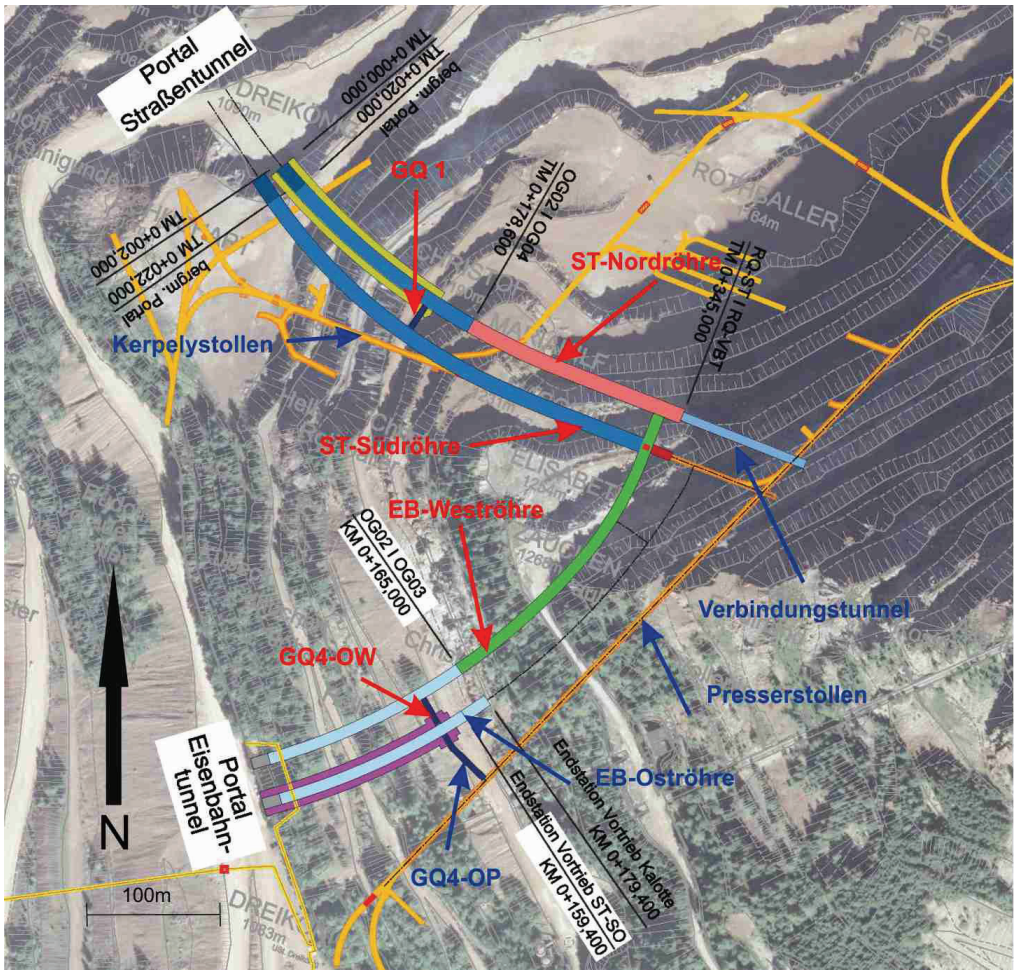

Abb. 11. Übersichtsbild über die neu aufgefahrenen Strecken im ZaB.

Die voll ausgestatteten Straßen-, Eisenbahn- und Versuchstunnel erlauben unterschiedlichste Trainingsmöglichkeiten und Versuchsdurchführungen für Einsatzkräfte, sowie für Betriebs- und Instandhaltungspersonal. Damit soll entscheidend zur Erhöhung der Sicherheit von Nutzern von unterirdischen Verkehrsanlagen beigetragen werden. Anhand von Schulungen soll auch die Instruktion von Service- und Instandhaltungspersonal stattfinden und die praktische Ausbildung für facheinschlägige Berufe angesiedelt werden.

Digitalisierung ist ein Schlüssel, um den konventionellen Tunnelbau „smart“ zu gestalten. Forschungsgruppen am Lehrstuhl arbeiten mit neuesten Technologien an innovativen und nachhaltigen Lösungen von morgen. Dabei wird die digitale Transformation der neuen österreichischen Tunnelbaumethode (NÖT) interdisziplinär vorangetrieben. Das Zentrum am Berg dient dabei als Forschungsstätte zur Evaluierung dieser neuen Methoden und zur Erprobung neuerster Technologien. Mittels Laserscanverfahren werden Punktwolke-Daten erzeugt und durch den Einsatz von Algorithmen aus der künstlichen Intelligenz zu einem Bild verarbeitet. Dies ermöglicht eine Objekterkennung ähnlich einem herkömmlichen Foto. So können Objekte nicht nur identifiziert, sondern auch mit Metadaten versehen werden. Die Vision ist es, jede noch so kleine Komponente im Tunnel mit der jeweiligen Historie zu hinterlegen. Die Abfrage dieser Information ist durch einen simplen Mausklick oder mittels Wimpernschlag durch eine Datenbrille jederzeit visualisierbar. Um die Vision umsetzen, arbeiten wir am Lehrstuhl auch mit jungen kreativen Start-up Unternehmen aus ganz Österreich zusammen.

5. Genese der Vererzung

Im Interaktiven Rohstoffinformationssystem der Geologischen Bundesanstalt (IRIS; https://iris.geologie.ac.at) wird der Erzberg mit 157 weiteren Eisen- (z.B. Radmer) und Buntmetallvorkommen (z.B. Kalwang, Radmer) und ehemaligen Lagerstätten dem Eisenerzbezirk (Eisenkarbonat/Kupfer) Norische Decke (Steirischer Erzberg) zugeordnet. Diesen Vererzungen gemein sind die Position innerhalb der paläozoischen Gesteine der Norischen Decke, das häufige Auftreten von Fe-Karbonaten sowie, soweit untersucht, eine ähnliche Fluidchemie. Unterschiede bestehen in der Mineralogie, Spurenelementzusammensetzungen und Form der Erzkörper von schichtgebunden, stratiform über wolkig-diffus bis zu Gangerzen.

Die Genese des Steirischen Erzberges sowie der kleineren Eisenerzvorkommen in der näheren Umgebung wurde viel und heftig diskutiert (REDLICH, 1922; HIESSLEITNER, 1929; REDLICH & PRECLIK, 1930; THALMANN, 1974, 1978; BERAN, 1975, 1977, 1979; SCHULZ & VAVTAR, 1991; SCHULZ et al., 1997; POHL & BELOCKY, 1999; PROCHASKA, 2012, 2016). Eine wichtige Beobachtung ist, dass alle Gesteine im Lagerstättenbereich - vom Porphyroid bis in die Präbichlbrekzie - von einer Mineralisationsphase betroffen sein können. Die ursprüngliche Idee war eine Metallbringung basierend auf einer epigenetisch hydrothermalen Metasomatose im Zuge der alpidischen Orogenese. REDLICH (1922) vermutete ein junges Vererzungsalter und betrachtete die im Hangenden der Vererzung auftretenden Werfener Schichten als Permeabilitätsgrenze für aufsteigende metallhaltige Lösungen. Er stufte die Vererzung des Steirischen Erzberges als „sehr jung, das heißt nach der letzten gebirgsbildenden Bewegung“ ein. Der Erzanreicherungsprozess sei metasomatischen Ursprungs. Der Transport der Eisenionen (und untergeordnet auch Mangan- und Magnesiumionen) müsste über fluide Phasen über ein Kluftsystem erfolgt sein. Durch Reaktion mit diesen wurde eine Verdrängung der Ca-Ionen und die Bildung von Siderit bzw. Ankerit angenommen. Die zweite Erklärung der Vererzung geht von einer primär sedimentären Bildung durch submarine Exhalation von Fe-haltigen hydrothermalen Lösungen in einen flachmarinen karbonatischen Ablagerungsraum aus (SCHULZ et al., 1997). Von THALMANN (1978) aus der benachbarten Sideritlagerstätte Radmer beschriebene feinschichtig gebänderte Siderittexturen wurden als Hinweis auf Relikte einer paläozoischen schichtgebundenen Sideritvererzung interpretiert. Basierend auf gefügekundlich-petrographischen Befunden wurde die Lagerstätte daher als Produkt polygenetischer Entwicklung dargestellt, beginnend mit der prä-permischen extern-sedimentären Anlagerung von Fe-Karbonaten in devonischen Gesteinen; die dominierenden kristallinen Erzlagenbaue (Sideritmarmore) werden durch selektive diagenetische Abbildungskristallisation und variszische sowie oberkretazische Metamorphose erklärt.

Eine erste geochronologische Datierung der Siderit-Ankeritgesteine mittels der Sm-Nd Isotopenmethode an Karbonat ergab ein obertriassisches Alter (208 ± 22 Ma; PROCHASKA & HENJES-KUNST, 2009, Abb. 12). In Verbindung mit fluidchemischen Daten und einer auffallenden Ähnlichkeit zu den Magnesitlagerstätten in paläozoischen Gesteinen des Ostalpins wird nun eine postvariszische, aber präalpidische epigenetische metasomatische Verdrängung der devonischen Karbonatgesteine durch hochtemperierte (300–400 °C) evaporitische Lösungen angenommen (PROCHASKA, 2012, 2016). Die mineralisierenden Fluide stellen aufgrund ihrer stark halitfraktionierten Zusammensetzung evaporitische, residuale Meerwässer mit hoher Salinität (bis zu 23 % NaCl-Äquivalent) dar (PROCHASKA et al., 2010). Solch hochsalinare, reduzierende und saure Fluide lösten während ihrer Zirkulation in der Trias Metalle aus dem variszisch deformierten und metamorph überprägten ostalpinen Deckenstapel.

Beim Aufstieg der Lösungen bildete sich durch Umwandlung von Kalkstein bei niedrigen Temperaturen Magnesit aus Fe-freien Lösungen. Gesteins-Fluidwechselwirkungen führten zur Anreicherung von Fe und zur metasomatischen Bildung von Siderit und Ankerit aus höher temperierten Lösungen. Aufgrund der komplexen Texturen und Mineralparagenese (Abb. 9) ist von einer mehrphasigen Vererzung auszugehen. Metasomatische Prozesse während und sogar nach der kretazischen Orogenese, die im Lagerstättenbereich Temperaturen von etwa 300 °C erreichte, sind anzunehmen. Letztlich belegen die geologisch sehr jungen Alter der Erzbergite und assoziierten Dolomite die anhaltende Dynamik am und im „Steirischen Brotlaib“.

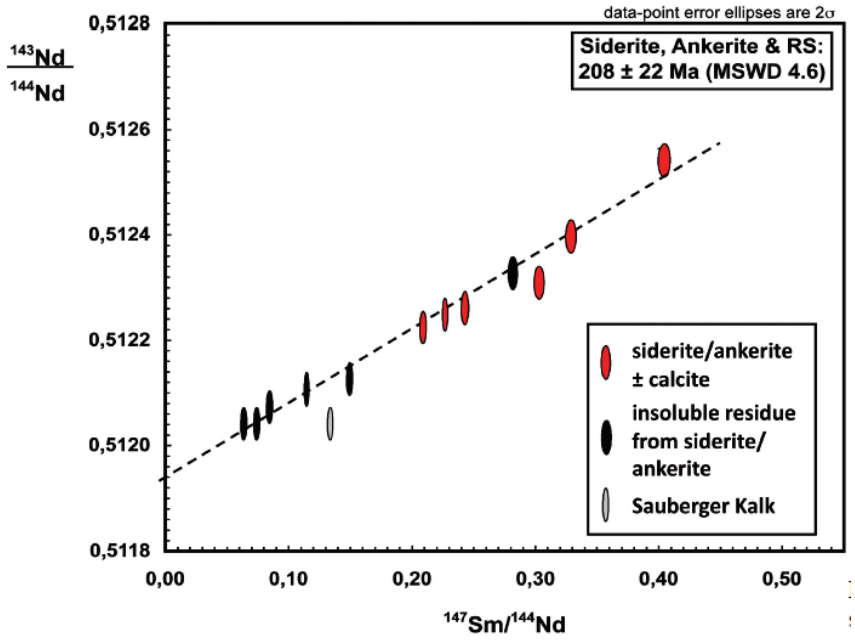

Abb. 12. Sm-Nd-Isochronendiagramm von Siderit, Ankerit und deren unlöslichen tonigen Rückständen von Proben vom Steirischen Erzberg (PROCHASKA & HENJES-KUNST, 2009).

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Aflenzer Bürgeralm-Panorama-Straße – Ein spektakulärer Profilschnitt durch die Gesteine der Trias am Südrand der Mürzalpen-Decke (Nördliche Kalkalpen)

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Einleitung

Die eintägige Exkursion startet in den stratigraphisch jüngsten Anteilen der Norischen Decke und führt danach entlang der Panoramastraße auf die Aflenzer Bürgeralm. Nach einer Einführung in die Regionalgeologie und Tektonik des Gebietes werden die entlang der Panoramastraße bestens aufgeschlossenen Gesteine am Südrand der juvavischen Mürzalpen-Decke vorgestellt. Dabei soll besonders die Fazies und stratigraphische Stellung der Gesteine sowie die zeitlich-räumliche Entwicklung ihres Ablagerungsraumes im Vorfeld der Trias-Karbonatplattformen diskutiert werden.

Introduction

The one-day excursion starts in the stratigraphically youngest parts of the Noric nappe, leads along the panorama road to the Aflenzer Bürgeralm and afterwards – in good weather – on foot to the Schönleitenhaus. After an introduction to the regional geology and tectonics of the area, the rocks at the southern edge of the juvavic Mürzalpen nappe, which are best exposed along the Panoramastraße, will be presented. Especially the facies and stratigraphic position of the rocks as well as the temporal-spatial development of their depositional environment in the forefront of the Triassic carbonate platforms will be discussed.

Regionalgeologische Übersicht

Das Exkursionsgebiet befindet sich am Südrand der Nördlichen Kalkalpen wo sich auf engem Raum mehrere Decken des oberostalpinen Deckenstapels (SCHMID et al., 2004) überlagern (Abb. 1/Fig. 1).

Am Südrand des Exkursionsgebietes tritt die Troiseck-Flonig-Decke als Teil des Silvretta-Seckau-Deckensystems zu Tage. Sie wird überwiegend aus primär variszisch amphibolitfaziell metamorphem Paragneis mit Amphibolitlagen (tw. Granatamphibolit und Granat Glimmerschiefer), eingeschaltetem leukokratem, tw. porphyrischem Granitgneis, Albitgneis sowie aus geringmächtigen Pegmatigneis-Lagen aufgebaut, die zum Troiseck-Komplex zusammengefasst werden (SCHUSTER & NOWOTNY, 2015). Für den Gesteinsbestand aus Paragneis und Amphibolit konnte ein kambrisches bis unterdevones Eduktalter, für den leukokraten Granitgneis ein oberdevones Eduktalter ermittelt werden (BRYDA et al., 2020).

Die Gesteine des Troiseck-Komplexes werden von porphyrischen Metarhyolithen und Metakoglomeraten, –arkosen und Serzizitschiefern („Alpiner Verrucano“) des Permiums diskordant überlagert. In der Untertrias folgt typisch entwickelter Semmeringquarzit und in der Mitteltrias dunkelgrauer (Anisium) und hellgrau-rosa gefärbter (Ladinium) Calcit-Marmor = „Thörler Kalk“ (TOLLMANN, 1977: 223 – 230). Diese Metasedimente werden zum „Thörler Zug“ zusammengefasst und wurden im Zuge der eoalpinen Orogenese unter den Bedingungen der unteren Grünschieferfazies metamorph. Diese Metamorphose führte auch zu einer retrograden Überprägung der unterlagernden Gesteine des Troiseck-Komplexes (SCHUSTER & NOWOTNY, 2015).

Über der Troiseck-Flonig-Decke folgen die Decken des Grauwackenzone-Deckensystems, mit der Veitsch-Decke in tektonisch liegender und der Silbersberg-Decke in tektonisch hangender Position (NEUBAUER et al., 1994). Die Veitsch-Decke (RATSCHBACHER, 1984) besteht im Exkursionsgebiet zum überwiegenden Teil aus Graphit reichen Schiefern und Metasandsteinen bis –Konglomeraten der Sunk-Formation (Oberkarbon), geringmächtigen Calcit-Marmor-Züge der Triebenstein-Formation und am

Mitterberg bei Palbersdorf aus geringmächtigen Metatuffiten (MAYER & NISCH, 2011). Die lateral nicht aushaltende Silbersberg-Decke setzt sich im Raum Aflenz aus Quarzphyllit und Metakonglomeraten und –Sandsteinen des Permiums zusammen und wurde aufgrund ihrer geringen Mächtigkeit nicht in Abb. 1 dargestellt.

Über dem Grauwackenzone-Deckensystem folgt die Norische Decke die bereits Teil des Tirolisch-Norischen Deckensystems ist. Ihre Basis wird durch die mächtigen Metagrauwacken bis Phyllite der Gerichtsgraben-Formation (oberes Ordovizium und älter?; HUBMANN et al., 2014) aufgebaut, die auch geringmächtige Grünschiefer und saure Metatuffe enthalten können. Darüber folgt noch im oberen Ordovizium der primär aus Ignimbriten bestehende, dazitisch-rhyolitische Blasseneckporphyroid (HEINISCH, 1980) als Leitgestein der Norischen Decke, das besonders westlich Aflenz-Kurort große Areale einnimmt. Im Hangenden des Blasseneckporphyroids tritt im Gebiet von Kartenblatt GK102 Aflenz Kurort (BRYDA et al., 2020) eine gegenüber der Umgebung von Eisenerz (BRYDA & VAN HUSEN, 2010; BRYDA et al., 2013) reduzierte Schichtfolge auf. Diese besteht aus den Gesteinen der Rad-Formation (oberstes Ordovizium bis unteres Devonium), an deren Basis teilweise noch sehr geringmächtiger Polsterquarzit (Oberordovizium) auftreten kann und dunkelgrauen wie hellgrauen gebänderten Calcit-Marmoren, die teilweise ankeritisch-sideritisch vererzt sind und überwiegend dem Devonium angehören dürften (Kaiserstein-Formation, NIEVOLL & SUTTNER, 2015). Eindeutig in das Silurium zu stellende Karbonate konnten nicht nachgewiesen werden, zahlreiche Conodontenproben brachten kein Ergebnis.

Im Permium transgredieren die klastischen Präbichl Schichten (Präbichl-Formation; HUBMANN et al., 2014) im unteren Permium diskordant den durch die variszische Orogenese deformierten älteren Gesteinsbestand und gehen im Hangenden noch in die feinklastischen Werfener Schiefer des unteren Anisiums über, die die Schichtfolge der Norischen Decke abschließen. Sowohl der Gesteinsbestand des Grauwackenzone-Deckensystems als auch jener der Norischen Decke war im Verlauf der eoalpinen Orogenese von einer penetrativen grünschieferfaziellen Metamorphose betroffen (NEUBAUER et al., 1994).

Die Norische Decke wird an breiter Front durch die Gesteine der juvavischen Mürzalpen-Decke überlagert, die den gesamten Kalkalpen-Südrand aufbauen. Die Überschiebungsfläche der Mürzalpen-Decke verläuft dabei über weite Strecken innerhalb der Werfener Schichten und wird dort nur durch lückenhaft auftretendes Haselgebirge mit Gips-Anhydritkörpern (oberes Permium) und entsprechenden Rauwacken markiert. Über den vorwiegend siliziklastischen Seichtwasserablagerungen der Werfener Schichten (untere Trias) folgen ca. 2000 bis 2500 m mächtige Karbonatsedimente (Kalke und Dolomite) einer Karbonatrampe (Steinalm-Karbonatrampe des Anisiums) und drei, aufeinander folgenden Karbonatplattform-Entwicklungen (Wettersteinkalk-Karbonatplattform des Ladiniums bis unteren Juliums, Waxeneckkalk-Karbonatplattform des oberen Karniums und Dachsteinkalk-Karbonatplattform des Noriums bis Rhaetiums) mit den entsprechenden Riffhang und Beckensedimenten (KRYSTYN et al., 1990; MANDL, 2000).

Die Steinalmkalk-Karbonatrampe entwickelt sich über tiefer anisischen Dolomitlaminiten – „Anisdolomit“ und besteht aus lagunären Kalken des Pelsoniums. Diese erste Karbonatrampe ertrinkt im Zuge der Reiflinger Wende (SCHLAGER & SCHÖLLNBERGER, 1974) im oberen Pelsonium und wird durch schwarzen Hornsteinknollenkalk der Reifling-Formation überlagert. Im Ladinium bis unteren Julium folgt allodapischer Bankkalk der Grafensteig-Formation der über dickbankige Vorriffsedimente in den Wettersteinkalk in Riff- und Lagunenfazies der Wettersteinkalk-Karbonatplattform überleitet (BRYDA et al. 2013). Große Teile dieser Karbonatplattform liegen heute in dolomitisierter Form als Wettersteindolomit vor.

Nach dem Niedergang der Karbonatproduktion der Wettersteinkalk-Karbonatplattform im untersten Julium, lagerten sich im oberen Julium auf der Plattform geringmächtige Tonschiefer und schwarze Biogenschuttkalke der Leckkogel-Formation ab (DULLO & LEIN, 1982; LEIN, 2010), die nur lückenhaft erhalten und mit undeutlich gebanktem, lagunären Dolomit vergesellschaftet sind. Dieser Dolomit (Waxeneckdolomit) tritt auch im Hangenden im oberen Karnium (Tuvalium) bis vermutlich untersten Norium (Lacium) auf und wird als Teil der Waxeneckkalk-Karbonatplattform (KRYSTYN et al., 1990) angesehen.

Am Top des Waxeneckdolomites treten südöstlich Fölzsattel 1626m lückenhaft bunte Kalke mit Conodonten des Noriums (Alaunium) auf, die dann an dieser Stelle von norischem Dachsteinkalk in Riff-Fazies der ausgedehnten Dachsteinkalk-Karbonatplattform (Norium bis Rhaetium) überlagert werden. Ab dem Karlhochkogel geht der Dachstein-Riffkalk in gebankten lagunären Dachsteinkalk über. In den nach Südosten exponierten Dachsteinkalkwänden der Mitteralm und des Feistringsteines tritt Dachsteinkalk in Vorriff-Fazies auf. Am Feistringstein deutet sich, durch die Progradation des Dachsteinkalkes in Vorriff-Fazies über die Bankkalke der Aflenz-Formation (oberes Norium), bereits der Faziesübergang zu den Hang- und Beckensedimenten des Aflenzer Triasbeckens an (LOBITZER, 1974).

In diesem werden im unteren Karnium (Julium) über den ladinischen Slopesedimenten (Grafensteig-Formation) der Wettersteinkalk-Karbonatplattform die gemischt pelitisch-karbonat(biolitho)klastischen Sedimente der Leckkogel-Formation in größerer Mächtigkeit abgelagert (LEIN, 2010). Darüber folgen im oberen Karnium dunkle Bankdolomite (Jauring-Formation; RICHOZ et al., 2015) und dolomitisierte Brekzien (Mannsteinwald-Formation) die im Norium von Hornstein führenden Bankkalk und Bankdolomit (Pötschen-Formation) sowie Bankkalk der Aflenz-Formation überlagert werden (BRYDA et al., 2020). Zlambachmergel des Rhaetiums konnten im Aflenzer Raum nicht nachgewiesen werden.

Cononten aus Gesteinen der Mürzalpen-Decke erreichen hohe CAI-Werte von 5.0 bis 7.0 und lassen auf eine höher anchizonale bis grünschieferfazielle Metamorphose schließen (GAWLICK et al., 1994, LEIN & GAWLICK, 2001; BRYDA et al., 2008). Durch Untersuchungen kohlenstoffreicher Partikel innerhalb der Reingrabener Schiefer und von Conodonten aus dem Aflenzer Triasbecken mit Hilfe der Ramaspektroskopie konnte die maximal erreichte Temperatur auf Werte von 280-310 °C eingeengt werden (RANTITSCH et al., 2020).

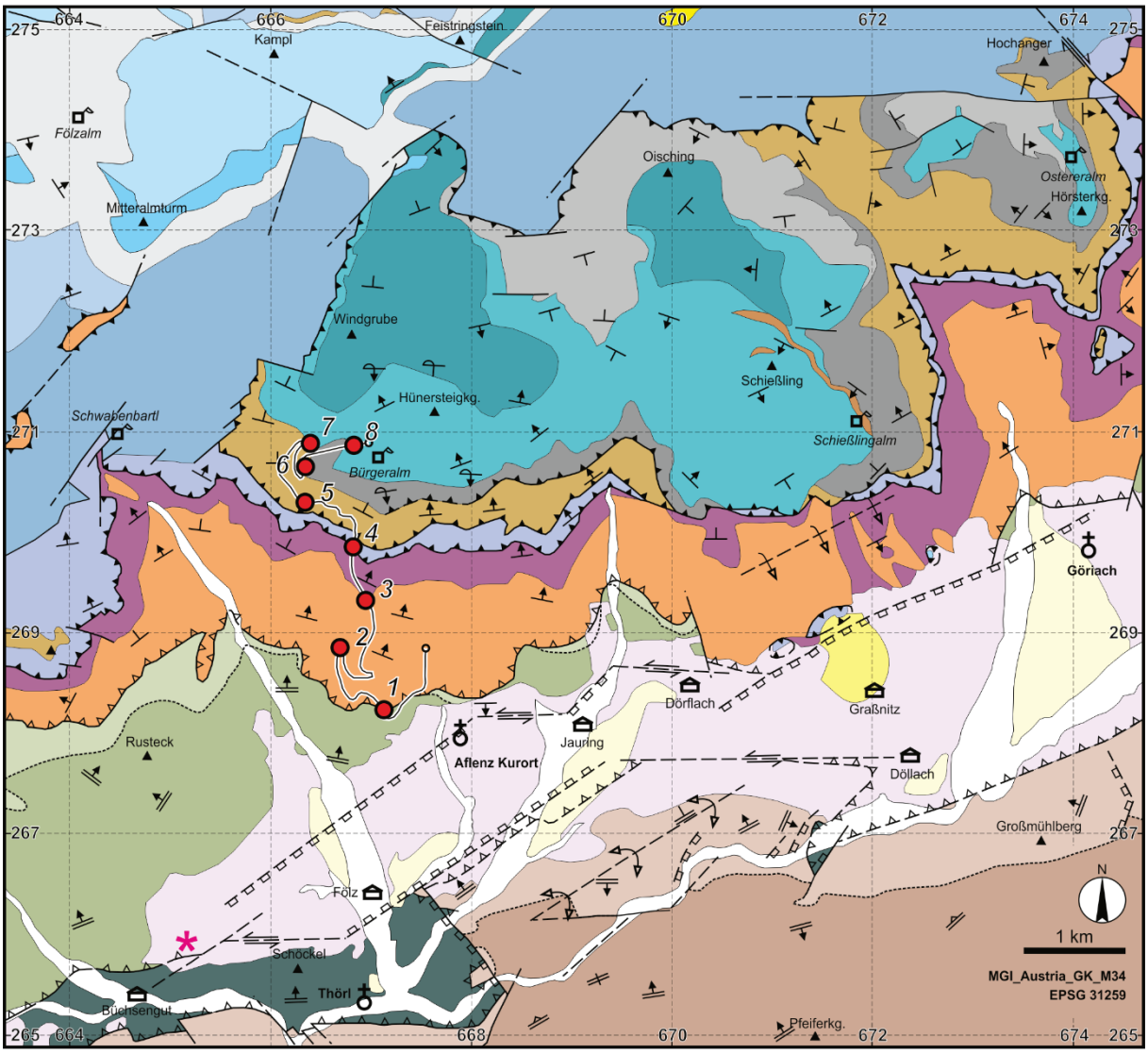
Die Ortschaft Aflenz Kurort ist auch namensgebend für das „Aflenzer Neogenbecken“, das sich als zusammengesetztes Pull-Apart-Becken (REISCHENBACHER & SACHSENHOFER, 2002, SACHSENHOFER et al. 2003) über eine Länge von ca. 16 km von Etmißl bis in den Bereich Turnau erstreckt und eine maximale Breite von 2km erreicht. Das Becken setzt sich aus mehreren Teilbecken zusammen, die über ein System aus begrenzenden Linksseitenverschiebungen und Abschiebungen miteinander verbunden sind. Diese wurden im Zuge der miozänen Extrusionstektonik angelegt und führten südlich Aflenz Kurort zu einer Absenkung von ca. 500m (GRATZER et al., 2001).

An der Beckenbasis treten ab dem Tal des Fölzer Baches fluviatile Sedimente (Schwemm- und Murenfächer, Kies, Sand, Ton) der Feistring-Formation auf, die den Beckenuntergrund diskordant überlagen und im zentralen Beckenbereich bis zu 300 m Mächtigkeit erreichen. Diese Sedimente enthalten eine endemische Süßwasser Molluskenfauna (überwiegend Gastropoden aber auch Bivalven; HARZHAUSER et al. 2012).

Im Hangenden folgen die Sedimente der Göriach-Formation, die weiter in die Sulzgraben-Subformation und in die Groisenbach-Subformation gegliedert werden kann. Die ca. 200m mächtige Groisenbach-Subformation wurde dabei unter lakustrinen Bedingungen abgelagert und besteht aus feinkörnigen Seesedimenten. Der enthaltene Diatomit war zuletzt in den 1980er Jahren Ziel eines Prospektionsprogrammes.

Die an der Basis der Groisenbach-Subformation in mehreren Flözen auftretende Braunkohle wurde in einem Bergbau bei Göriach bis in die 1950er Jahre abgebaut. Aus diesem Abbau ist sowohl eine artenreiche Flora als auch eine bedeutende miozäne Wirbeltierfauna des Unteren bis Mittleren Badeniums bekannt geworden (THENIUS, 1949:753ff; MOTTL, 1970:108ff.). Diese Alterseinstufung konnte durch HAJÓS (1972) über eine Diatomeen-Flora bestätigt werden.

Westlich des Fölzbaches verzahnt die limnische Groisenbach-Subformation über ein Delta-Regime mit der rein fluviatilen Sulzgraben-Subformation. In dieser Subformation wurde im Zuge der Neuaufnahe des Kartenblattes GK102 Aflenz Kurort von S. Ćorić im Sulzgraben ein Glastuffvorkommen entdeckt, das über Zirkon-Alter (untere, vergrünte Tufflage: 14,7 ± 0,1 Ma; obere, frische Tufflage: 14,1 ± 0,2 Ma) in den Grenzbereich Unteres-Mittles Badenium bzw. Mittleres Badenium (höheres Langhium) eingestuft werden konnte (IGLSEDER et al., 2022, dieser Band). Das radiometrisch Alter der Tuffvorkommen im liegenden Teil der Schichtfolge des Aflenzer Beckens deckt sich daher sehr gut mit den biostratigraphisch ermittelten Altersdaten.



Quaternary deposits
- Alluvial deposits; Holocene
- Niederterrasse; Würm Glacial
- Moraine; Würm Glacial
- Talus (part. consolidated, loamy)

Intramontane basins

Aflenz Basin (Miocene)
- Fluv. clastics, coal, shale, diatomite

Juvavic Nappe System

Mürzalpen Nappe
- Dachstein Lmst. (reef- / fore-reef facies)
- Waxeneck Dol.
- Aflenz Fm.
- Pötschen Lmst. and Dol. Intercalations of brown shale
- Mannsteinwald Fm.
- Jauring Fm.
- Leckkogel Fm.
- Wetterstein Lmst. & Dolomite (lagoon / reef & fore-reef facies)
- Reifling and Grafensteig Fms.
- Anisian Dolomite & Steinalm Fm.
- Werfen Fm.

Tirolic-Noric Nappe System

Noric Nappe
- Permo-Mesozoic Cover
- Paleozoic Basement

▲ Peak Village

Church Alpine hut

Bürgeralm Panorama Str.

Greywacke Zone Nappe System
- Silbersberg & Veitsch Nappe

Silvretta Seckau Nappe System

Troiseck-Floning Nappe
- Permo-Mesozoic Cover
- Crystalline Basement

1 **Excursion points** * Volc. tuff

Bedding >5°- 30° - 60° - 60° overt.

Foliation >5°- 30° - 60° - 85° - 90°

Unconformity Fault (c., i.)

Normal fault (certain, inferred)

Strike-slip fault (certain, inferred)

Nappe boundary (certain, inferred)

Thrustplane (certain, inferred)

Anticline, Monocline

Abb. 1. Vereinfachte geologische Karte des Aflenzer Beckens und des Mitteralm – Bürgeralm Gebietes.
Fig. 1. Simplified geological map of the Aflenz Basin and Mitteralm – Bürgeralm area.

Exkursionspunkte

Punkt 1 – Parkplatz bei Gasthof Pierer, 968m ü. A.

Geologische Übersicht – Top der Norischen Decke, Kontakt zu den Werfener Schichten der Mürzalpen-Decke

Am Startpunkt der Exkursion, sind im Umfeld des Gasthofes Pierer, einige typische Schichtglieder der Norischen Decke aufgeschlossen. Am Forstweg, der von der Bürgeralm-Panoramastraße im Bereich der Kehre südwestlich des Gasthofes abzweigt, trifft man auf graugrünen Blasseneckporphyroid (oberes Ordovizium, HEINISCH, 1980). Dieser wird durch geringmächtige grau bis grünlichgrau gefärbte, feinkörnige (Quarz)Wacke und durch Serizit silbrig glänzenden Quarzphyllit der Rad-Formation (oberstes Ordovizium bis unteres Devonium) überlagert, die im Wiesengelände um den Gasthof ansteht. Die besten Aufschlüsse befinden sich am Ausgangspunkt der Forststraße, die knapp unterhalb des Mautschrankens bei 961m SH nach WNW abzweigt.

Die Rad-Formation stellt an diesem Punkt das jüngste Schichtglied der Norischen Decke dar, wird in zahlreichen Profilen nahe Aflenz Kurort jedoch noch von dunkelgrau bis hellgrau gefärbten, feinkörnigen Bändermarmoren der Kaiserstein-Formation (NIEVOLL & SUTTNER, 2015) überlagert, die teilweise ankeritisch-sideritisch vererzt sind und die Basis der transgressiv darüber folgenden, grobklastischen Präbichl-Formation (oberes Permium, HUBMANN et al., 2014) bilden. Sowohl der Komponentenbestand als auch die dominanten Korngrößen des liegenden, gröber klastischen Anteils der Präbichl-Formation sind deutlich vom lokalen Untergrund abhängig. Im Typusprofil am Präbichl bei Eisenerz, Stmk. folgen über den Brekzien Quarz dominierte Konglomerate und Grobsansteine, die als handender Anteil der Präbichl-Formation betrachtet werden. Mit unscharfer Grenze folgt darüber überwiegend rot-violett gefärbter Silt-Feinsandstein, der bereits zu den Werfener Schichten der Norischen Decke gestellt wird. Im Zuge der Aufnahmearbeiten für Kartenblatt GK102 Aflenz konnte jedoch innerhalb der rotvioletten Silt- und Feinsandsteine eine zweite mächtigere Einschaltung von lithologisch den Präbichl-Formation gleichenden Brekzien und Grobsandsteinen auskartiert werden. Auf entsprechende Profile trifft man im Bereich Riegnereck, am langgezogenen Rücken, der nordwestlich des Hubostingbaches zum Alpspitz zieht und am Hang östlich St. Ilgen (An dieser Stelle enthalten die liegenden Präbichl-Formation bis zu 3 mm große Chloritoid-Kristalle).

Im Gelände konnten bis jetzt keine Hinweise auf eine tektonische Wiederholung der Präbichl-Formation gefunden werden – damit dürfte es sich bei diesen um eine sedimentäre Einschaltung handeln. Die rotvioletten Silt- und Feinsandsteine wären daher noch in den Schichtbestand der Präbichl-Formation einzubeziehen – die Abgrenzung zu den Werfener Schichten (untere Trias) erscheint problematisch!

Bei der Mächtigkeit der Präbichl-Formation ist vom Eisenerzer Raum nach Osten eine deutliche Abnahme der Mächtigkeit festzustellen. Östlich des Fölzer Baches sind sie am Top der Norischen Decke nur mehr lückenhaft erhalten und fehlen bei Punkt 1 vollständig.

Die Werfener Schichten setzen hier unmittelbar oberhalb der Rad-Formation ein und definieren den Verlauf der Deckengrenze von der hangenden Mürzalpen-Decke zur liegenden Norischen Decke.

Westlich des Fölzer Baches wird der Verlauf der Deckengrenze durch mehrere Einschaltungen von Haselgebirge (oberes Permium) markiert. Die bedeutendste davon wird in einem großen Gips-Anhydrit Tagebau im Haringgraben nordöstlich Tragöß abgebaut.

Punkt 2 – Bürgeralm-Panoramastraße, 1. Kehre, 1044 m ü. A.

Werfener Schichten an der Basis der Mürzalpen-Decke mit Karbonateinschaltungen

Die Werfener Schichten (untere Trias) der Mürzalpen-Decke bestehen zu einem großen Teil aus überwiegend hellgrün gefärbten, ebenflächigen dünn- bis mittelbankigen Silt- und (Quarz)Feinsandsteinen, die im Gebiet nördlich Aflenz-Kurort eine geschätzte, abnormal hohe Mächtigkeit von ca. 600m erreichen. Besonders an der Basis der Schichtfolge kommen aber auch noch wechselnd grau-rotviolett und grün gefärbte Typen vor. Im Aflenzer Raum enthalten die Werfener Schichten bereits im Liegenden Abschnitt karbonatgebundene Sandsteinlagen und geringmächtige Lagen aus roten Ooidkalken (z.B. an der Forststraße 200 m NW Gasthof Pierer), die in anderen Profilen auf den hangenden Abschnitt beschränkt sind. Häufig sind auch geringmächtige Lagen mit Bivalvenschill zu beobachten, die als Tempestit-Ablagerungen angesprochen werden können.

Punkt 3 – Bürgeralm-Panoramastraße, 1177m ü. A.

Typischer Werfener Kalk am Top der Werfener Schichten und scharfer Übergang in den „Anisdolomit“

Im hangenden Abschnitt der Werfener Schichten (untere Trias) vollzieht sich in Form des Werfener Kalkes (oberes Olenekium) ein Wechsel von vorwiegend siliziklastischer zu Karbonat dominierter Sedimentation. Im Aufschluss zeigt sich der Werfener Kalk als meist dünn- bis mittelbankiger, gelblichbraun bis grau anwitternder, ebenflächiger, im Anbruch mittelgrau bis dunkelgrauer, tlw. sandiger Kalk mit variabel mächtigen Tonschiefer und Mergel Zwischenlagen. Kalk-Mergel-Wechsellagen kommen vor.

Die Kalkbänke weisen eine große Bandreite von Mikrofaziestypen auf, die von Mudstone über Wackestone bis Grain- und Rud- bis Floatstone reicht, die auf stark schwankende energetische Bedingungen innerhalb des im Flachwasser gelegenen, küstennahen Ablagerungsraumes zurückzuführen sind. Teilweise sind in den Kalkbänken typische Sturmlagen mit Lumachellen (Bivalven, Gastropoden) erkennbar, Ooidkalke und Crinoidenkalke sowie bioturbierte, mikritische Kalktypen kommen vor (SCHNEDLITZ, 2017).

Am Top der Werfener Schichten auf dem Kartenblatt erreicht der Werfener Kalk eine maximale Mächtigkeit von ca. 100 m, kann aber auch – vermutlich tekonisch bedingt – reduziert sein, vollständig aussetzen oder nur über kurze Strecken, als Linse erhalten sein. In dem bei Punkt 3 aufgeschlossenen Werfener-Profil ist der Werfener Kalk in zwei, durch Werfener Schiefer voneinander getrennten Zügen aufgeschlossen. Im Bürgerbachtal und besonders östlich der Ortschaften Untere- und Obere Au treten im Liegenden des obersten Werfener Kalkes mehrere schmale, gleichartig ausgebildete, lateral nicht weit verfolgbare Lagen von Werfener Kalk auf.

Im stratigraphisch Hangenden wird der Werfener Kalk an scharfer Grenze durch den „Anisdolomit“ (BRYDA et. al. 2013: 91f: Dunkle, laminierte Dolomite und Brekzien) überlagert, dessen maximale Mächtigkeit im Aflenzer Raum auf 220 m abgeschätzt werden kann.

An der Basis setzt der „Anisdolomit“ mit einem geringmächtigen Intervall aus dünnplattigem, schwarzem Bankdolomit ein. Darüber folgt variabel dünnschichtiger bis ca. 0,5 m gebankter, ebenflächiger, überwiegend dunkelgrau gefärbter, kleinstückelig zerfallender Bankdolomit. Dieser kann graue und weinrote Pelitlagen enthalten, die manchmal mehrere Dezimeter Mächtigkeit erreichen können. Einzelne, mächtigere Lagen können auch als dolomitischer Kalk ausgebildet sein und gelegentlich Anzeichen einer Verkieselung zeigen. Der Dolomit ist feingeschichtet bis laminiert; teilweise treten hellgraue Algenlaminite auf, ansonsten ist er fossilleer. In zahlreichen Profilen des Arbeitsgebietes löst sich der „Anisdolomit“ in eine intraformationelle Brekzie auf. Stratigraphisch reicht der Anisdolomit vermutlich vom oberen Olenekium (KRYSTYN, 1974) bis in den Grenzbereich Bithynium/Pelsonium (GAWLICK et al., 2021). Durch die auftretenden Algenlaminite und die Feinschichtung in Verbindung mit den Pelitlagen kann ein, mit dem Hauptdolomit des Noriums vergleichbarer, Ablagerungsraum im flachen Subtidal bis Supratidal? angenommen werden.

Da der „Anisdolomit“ sich in seiner faziellen Ausbildung und Gesteinscharakteristik deutlich von der Gutenstein-Formation unterscheidet, wurde dieser Begriff nicht verwendet.

Punkt 4 – Bürgeralm-Panoramastraße, 1228m ü. A.

Kurzer Profilabschnitt vom Kontaktbereich des Anisdolomites zur dolomitisierten Steinalm-Formation über die Reifling- und Gafensteig-Formation zur Leckkogel-Formation.

In vielen Profilen am Kalkalpen-Südrand folgt innerhalb der Mürzalpen-Decke im Hangenden des dunkelgrauen „Anisdolomits“ geringmächtiger, hellgrau gefärbter und meist mittel- bis dickbankiger Steinalmkalk des Pelsoniums. Dieser umfasst meist mehrere Mikrofaziestypen – von gut ausgewaschenen, bioklastischen Grainstones bis Rudstones über Mikrit reiche Typen (Mudstones – Wackestones) mit für den Zeitraum typischen Foraminiferen und Dasycladalen zu reinen Algenlaminiten (Bindstones) und ist als typisches Flachwassersediment, mit einem Ablagerungsbereich vom Subtidal bis in das Supratidal anzusprechen.

Im Aflenzer Raum konnte die Steinalm-Formation nur in den Profilen zwischen dem Ilgner Alpl 1506m im Westen und entlang der Südflanke der Bürgeralm bis westlich des Feistringgrabens nachgewiesen werden. In den anderen Profilen folgt die Grafensteig-Formation unmittelbar über dem „Anisdolomit“. Die Steinalm-Formation zeigt in diesem Abschnitt eine wechselnde Dolomitisierung, die im Bereich der Bürgeralmstraße im Steinalmniveau überwiegend nur mehr zuckerkörnigen Dolomit erkennen lässt. Ob die die Steinalm-Formation ab dem Feistringgraben vor der Ablagerung der Grafensteig-Formation erosiv entfernt worden ist, oder ob es sich hier um einen tektonischen Kontakt zum „Anisdolomit“ im Liegenden handelt, wäre noch zu klären. Im Bereich des Hochschwab enthalten graurosa gefärbte, pelagische Kalke der Sonnschien-Formation Komponenten aus „Anisdolomit“ und bilden dessen normale stratigraphische Überlagerung (BRYDA & VAN HUSEN, 2010, BRYDA et al., 2013).

Im stratigraphisch Hangenden der Steinalm-Formation folgt meist dunkelgrau bis schwarzer dünnbankiger und stark kieseliger Knollen- bis Plattenkalk (oberstes Pelsonium), der meist nur eine Mächtigkeit von wenigen Metern (<=5m) erreicht und als Äquivalent der Knollenkalk-Subformation der Reifling-Formation angesehen werden kann. Auch dieses Schichtglied kann in den Profilen nur bis zum Feistringgraben verfolgt werden und fehlt östlich davon.

Über der Knollenkalk-Subformation folgt ein intensiv graurosa bis rot gefärbter, mikritischer, welligschichtiger Bankkalk (Illyrium), der sich bankintern in Knollen auflöst, die teilweise ein gelblich-grünliches Zwischenmittel aufweisen, das möglicherweise als Tuffit anzusprechen ist. Dieser Kalktypus ist an der Basis der darüber folgenden Grafensteig-Formation (Ladinium bis Unteres Julium) in tektonisch nicht reduzierten Profilen nachweisbar und erreicht nur eine geringe Mächtigkeit von wenigen Metern. An der Basis des Hochschwab-Massivs werden diese graurosa Knollenkalke durch Kalke der dort mächtiger entwickelten Sonnschien-Formation vertreten. Auch dort folgt darüber hellgrau und dunkelgrau gefärbter, allodapischer Bankkalk der Grafensteig-Formation, der im Hangenden in hellen Schuttkalk und Vorriffschuttkalk der progradierenden Wetterstein-Karbonatplattform übergeht.

Die Kalke der Grafensteig-Formation im Aflenzer Bereich sind im liegenden Abschnitt teilweise noch graurosa gefärbt, mikritischer und teilweise dolomitisiert. Vom Ilgner Hocheck 1512m über das Ilgner Alpl 1509m bis etwa in den Bereich unterhalb Gsenk der Aflenzer Bürgeralm ist der Bankkalk auch deutlich allodapisch und enthält Hornsteinknollen. Gegen Osten wird der Kalk jedoch feinkörniger und ist im höheren Abschnitt einheitlicher hellgrau-weiß gefärbt. Dieser Typ steht auch an Punkt 4 der Bürgeralmstraße an. Der Trend zur Feinkörnigkeit nach Osten kann als Resultat zunehmender Distanz zum Liefergebiet der Wetterstein-Karbonatplattform angesehen werden und spiegelt sich auch in der geringeren Mächtigkeit der Formation in größerer Entfernung zur Karbonatplattform wieder. Allerdings sind die auffälligen Mächtigkeitsschwankungen der Grafensteig-Formation am Südrand des Kartenblattes GK102 Aflenz auf eine teilweise starke interne Deformation des Schichtgliedes und einen tektonischen Zuschnitt zurückzuführen.

Punkt 5 - Bürgeralm-Panoramastraße, Gsenk, 1312m ü. A.

Top der Grafensteig-Formation, erster Zug Reingrabener Schiefer (Halobienschiefer) mit gut gebanktem, hellgrauem allodapischem Kalk im Hangenden (Grafensteig- oder Leckkogel-Formation?)

Am Top des hellgrauen Bankkalkes der Grafensteig-Formation kann in den Profilen vom Ilgner Alpl bis in den Bereich der Aflenzer Bürgeralm ein dunkelgrau bis schwarz gefärbter Bankkalk mit

geringmächtigen Tonzwischenlagen nachgewiesen werden. Dieser Bankkalk erreicht nur eine Mächtigkeit von wenigen Metern und wird dann von den dunkelgrau bis schwarz gefärbten Reingrabener Schiefern und Mergeln (Halobienschiefer) überlagert. Die besten Aufschlüsse dieser Subformation befinden sich unmittelbar südlich des Gipfels der Ilgner Alm (1506 m) und im Eisental westlich Gsenk (Eisental-Subformation auf Kartenblatt Aflenz-Kurort). Im Bereich Gsenk sind diese Kalke nur lückenhaft erhalten – ein kleiner Aufschluss findet sich jedoch im Bereich der Westflanke des Grabens der östlich Gsenk verläuft.

Der Reingrabener Schiefer setzt im Hangenden der Grafensteig-Formation mit einem ca. ein Meter mächtigen kalkfreien Abschnitt ein, geht jedoch danach in Mergel mit geringmächtigen Kalkbänkchen über. Diese Abfolge ist auch bei den höheren Tonschieferzügen mit abweichender Mächtigkeit zu beobachten. Im Bereich Gsenk folgt über diesem ersten Tonschieferzug ein heller, allodapischer Bankkalk mit Hornsteinlagen, der dem Grafensteigkalk überaus ähnlich ist. Die aus diesem Bankkalk gewonnenen Conodontenproben (det. L. Krystyn) konnten in das Julium (Unterkarn) eingestuft werden – erlauben also keine zeitliche Differenzierung von der unterlagernden Grafensteig-Formation. Über jeweils drei Messungen mit einem tragbaren Röntgenspektrometer, die jeweils in geringer Entfernung voneinander in den beiden Einheiten gemessen wurden, konnte jedoch ein signifikanter Unterschied im Strontium-Gehalt zwischen dem Kalk der Grafensteig-Formation (Ø 142ppm) und den allodapischen Kalken im Hangenden der Reingrabener Schiefer (Ø 292ppm) festgestellt werden. Im Gelände kann der allodapische Bankkalk bis in den Bereich der Südost-Flanke des Eisentales verfolgt werden, ist im Tal selbst durch Schutt verhüllt und tritt in der Nordwest-Flanke wieder auf, wobei eine Korngrößenzunahme der allochthonen Komponenten (Brekzien) festzustellen ist. Im Streichen wird er bis zu diesem Punkt immer von Reingrabener Schiefer unterlagert. Aufgrund der beschriebenen Situation, wird dieser Bankkalkzug daher als erste, basale und älteste allodapische Einschaltung mit hellgrauem karbonatklastischen Material innerhalb der Leckkogel-Formation (DULLO & LEIN, 1982; LEIN, 2010) betrachtet, der im Bereich der Aflenzer Bürgeralm am weitesten nach Osten verfolgt werden kann.

Punkt 6 – Bürgeralm-Panoramastraße, Kehre bei 1400m ü. A.

Kurzes Profil durch den Hangenden Teil der Leckkogel-Formation mit Tonschiefer Horizonten und Olistolithen.

Ab dem zuvor beschriebenen Punkt 5 quert die Bürgeralmstraße eine mehrfache Abfolge von unterschiedlich mächtigen dunkelgrauen bis schwarzen Tonschieferlagen und meist dunkelgrauen, untergeordnet Hornstein führenden, allodapischen Bankkalken. Wie bereits bei LEIN (2010: 188-189; Stop 5-6) beschrieben, werden diese Bankkalke von sedimentären Brekzien begleitet und enthalten mehrfach Olistolithe aus hellen Seichtwasserkarbonaten sowie sogenannte „Cipit Blöcke“ aus dunkelgrauen bis schwarzen Fossilschuttkalken. Diese Brekzien treten auch im NW des Eisentales auf. In dieser Richtung ist vermutlich auch das Liefergebiet der Brekzien und allodapischen Kalke und damit der ehemalige Rand der Karbonatplattform im Oberen Julium zu suchen. Vergleichbare allodapische Bankkalke mit hellen Brekzienlagen sind auch im oberen Misitulgraben (Fortstraße zwischen 1370 m bis 1400 m), ca. 400 m im NNO der Ostereralm 1565m sowie ca. 150 – 200 m nördlich der Jagdhütte oberhalb des Rötelstein und südlich der Einmündung des Grabens, der von der Spinnerinn zum Seegraben herunterzieht, aufgeschlossen. Durch ihr Auftreten kann auch dort die ursprüngliche Lage des Plattformrandes im Norden oder Nordosten vermutet werden. In Richtung des Südrandes der Aflenzer Bürgeralm und auch des Schießling 1667 m, setzen die Brekzien aus und gehen in allodapische Kalke über.

Die in der Straßenkehre bei Punkt 6 aufgeschlossen dunkelgrauen bis schwarzen (Pyrit reichen) Reingrabener Schiefer entsprechen dem stratigraphisch höchsten Tonschieferniveau des Bürgeralmprofiles. Diese Tonschiefer lassen sich bis in die obere Kehre der Bürgeralmstraße bei Punkt 7, 1480m und danach als oberstes Tonschieferband unterhalb der Wandflucht des Ranstein, 1555m weiter nach Osten verfolgen. Conodontenproben der allodapische Bankkalke konnten in das Julium, die dem obersten Tonsteinniveau auflagernden Karbonate bereits in das Tuvalium eingestuft werden. Als Altersumfang der Leckkogel-Formation, mit den teilweise noch zu benennenden Subformationen, wird daher Oberes Julium angegeben.

Wie bereits von LEIN (2010: 183) festgehalten, kann die Vorstellung von SPENGLER (1920) einer ungestörten Plattform-Becken-Verzahnung im Bereich der Aflenzer Obertrias nicht mehr aufrechterhalten werden. Die am Ende dieser Arbeit (SPENGLER, 1920) in einer Karte dargestellten, weit in den Wetterstein(Ramsau)dolomit hineinreichenden Züge aus Reingrabener Schiefer konnten im Gelände nicht verifiziert werden! Bei dem von SPENGLER (1920) als Hauptdolomit angesprochenen Gestein handelt es sich überwiegend um dolomitisierte Sedimente eines submarinen Hanges bis Beckens (allodapische Bankdolomit und Brekzien) mit überwiegend oberkarnischem (Tuvalium) Alter.

Nördlich des Aflenzer Obertriasbeckens existieren jedoch über der fast vollständig dolomitisierten Wetterstein-Karbonatplattform geringmächtige (gesch. maximal 10 m) und lateral meist nur über kurze Distanz verfolgbare Ablagerungen des Karniums. Dabei handelt es sich um schwarze Reingrabener Schiefer und dunkelgraue bis schwarze, dünn bis mittelbankige Fossilschuttkalke – besonders häufig mit Calcispongien, die hellgrünen Glaukonit führen und gelblich anwittern. Sie entsprechen den Kalktypen, die in Form von „Cipit-Blöcken“ in den Hangsedimenten des Juliums des Aflenzer Triasbeckens auftreten. Am Top der nördlichen Wettersteindolomit-Plattform sind im Profil unterhalb des Festlbeilstein 1847 m oder am Sattel nördlich „Zeller Steig“ in geringem Abstand zueinander bis zu drei Einschaltungen aus schwarzen Schwammkalken in mittelgrauem Dolomit übereinander nachweisbar. Meist ist nur der stratigraphisch älteste Zug deutlich entwickelt und auch mit geringmächtigem Reingrabener Schiefer an der Basis vergesellschaftet. Die hangenden Züge sind meist geringmächtiger und stärker dolomitisiert, teilweise rot verfärbt. In dem zwischengeschalteten, mittelgrauen Dolomit sind häufig Onkoide zu beobachten, die lagunäre Fazies belegen. Zumindest dieser Teil des Dolomites ist daher in das obere Julium zu stellen. Die Fazies entspricht aber nicht jener der Kalkolistolithe in den Hangsedimenten des oberen Juliums der Bürgeralm. Diese Sedimente wurden vermutlich am oberen Hang oder in Riffen abgelagert, die heute nicht mehr erhalten sind. Im Hangenden der Schwammkalke folgt weiter lagunärer Dolomit, der im Liegenden des Dachsteinkalkes eine Mächtigkeit von bis zu 200m erreicht. In Analogie zur Entwicklung im Bereich der Schneealpe, kann dieser als dolomitisierter Rest der Waxeneckkalk-Karbonatplattform angesehen werden. Conodontendaten aus bunten Spatkalken an der Basis des Dachsteinkalkes nahe des Weges vom Fözsattels, 1626m auf die Mitteralm ergaben ein mittelnorisches Alter (Alaunium 1) und liefern daher sowohl einen Hinweis auf die stratigraphische Reichweite des lagunären Dolomits der Waxeneckkalk-Karbonatplattform im Liegenden als auch auf den Beginn der Entwicklung der Dachsteinkalk-Karbonatplattform im Hangenden.

Punkt 7 – Bürgeralm-Panoramastraße, Alte Trasse, Kehre bei 1480m ü. A.

Kontakt des obersten Tonschieferbandes zu dunkelgrauem Plattendolomit, gelblichem Mergel und dünnbankigem Plattenkalk der Jauring-Formation.

Im Hangenden des obersten Zuges aus Reingrabener Schiefer steht geringmächtiger (max. 20m), dunkelgrauer bis schwarzer, deutlich allodapischer, dünnbankiger und ebenflächiger, teilweise kieseliger, Hornsteinlagen führender Bankdolomit an. Dieser wird durch eine, nur wenige Meter mächtige Lage aus auffallend gelblich gefärbtem Mergel überlagert, die als Markerhorizont über weite Strecken verfolgt werden kann. Sie bildet die Basis eines dunkelgrauen, dünnbankigen bis in den Dezimeterbereich gebankten Plattenkalkes, der die Wandabstürze entlang der Südseite der Aflenzer Bürgeralm bis zum Feistringtal und unterhalb des Rahnbodens aufbaut. Danach ist er noch an der Ostflanke des Schießling und Westflanke des Hörsterkogels sowie unterhalb der Scheibenmäuer und im Plotschraben im Hangenden der Leckkogel-Formation. aufgeschlossen. Die beschriebenen Bankkalktypen wurden gemeinsam mit dem auffälligen Mergelband zur Jauring-Formation zusammengefasst und mit Hilfe von Conodonten (det. L. Krystyn) eine stratigraphische Reichweite vom Grenzbereich Julium/Tuvalium bis in das Tuvalium 2 (Oberes Karnium) ermittelt.

Über dem Plattenkalk der Jauring-Formation folgt im Bereich des Bürgeralm-Plateaus ein mittel- bis dickbankiger, Hornsteinlagen und große Hornsteine führender mittelgrauer Bankkalk (Pötschenkalk), der auch große Teile der Fürstkuppe, des Schießling und den Gipfelgrat des Hörsterkogels sowie die obersten Bereiche der Scheibenmäuer aufbaut. Stratigraphisch reicht dieser Bankkalk vom Tuvalium 3 (Oberstes Karnium) bis in den Grenzbereich des Alauniums zum Sevatium (Oberes Norium).

Die beschriebene Abfolge von Jauring-Formation und Pötschenkalk tritt im plattformabgewandten Teil des Aflenzer Triasbeckens auf. Nähert man sich dem ursprünglichen Plattformrand, so tritt im hinteren Feistringgraben im Liegenden des Pötschenkalkes ein dünnbankiger, allodapisch-feinlaminierter, teilweise Brekzienlagen enthaltender, dunkelgraubrauner Bankdolomit mit Conodonten des Tuval 2 auf. Dieser Bankdolomit vertritt hier offenbar die Jauring-Formation und enthält häufig Rutschfalten. Im Feistringgraben folgt über dem Bankdolomit eine massig wirkende, sedimentäre Brekzie, die dunkle, intern laminierte und helle, strukturlose Dolomitkomponenten enthält (Mannsteinwald-Formation). Im Bereich der Westflanke des Feistringtales ist in diesem Niveau ein mittelgrauer, massig wirkender, strukturloser Dolomit aufgeschlossen, der an manchen Stellen isolierte und zerglittende dunkle Dolomitbänke enthält. Bei diesem helleren Dolomittyp könnte es sich um ursprünglich feinkörnige helle Karbonatsande-Schlämme handeln, von einer oberkarnischen Plattform in das Aflenzer Triasbecken geschüttet worden sind. Sowohl der dunkelgraubraune Bankdolomit als auch die sed. Brekzien grenzen unmittelbar an den Wettersteindolomit in Riff-Fazies. Auch der Pötschenkalk wird in Plattformnähe durch gebankten Hornsteindolomit mit Rutschfalten und Brekzienlagen abgelöst (BRYDA et al., 2020).

Punkt 8 – Bürgerlam-Panoramastraße, Parkplatz bei 1530m ü.A.

Hornstein führender Pötschenkalk und Pöschendolomit.

Der große Parkplatz am oberen Ende der Bürgeralm-Panoramastraße wurde bereits innerhalb der Pötschen-Formation angelegt. An der auf der gegenüberliegenden Talflanke in Richtung Achnerriegel führenden Forststraße steht ein teilweise synsedimentär zerglittener, Hornstein führender Bankdolomit an. Am Hang oberhalb folgt ca. 60 bis 80 m oberhalb der Forststraße dünn- bis mittelbankiger, dunkel- bis mittelgrauer mikritischer Kalk der Aflenz-Formation, der teilweise kleine Hornsteinknollen führt. Diese Formation baut danach die höher gelegenen Areale oberhalb der Bürgeralm (Windgrube 1809 m, Lärchkogel 1719 m) auf und wird erst südlich des Zlacken Sattels 1743m von NO-SW streichenden Störungen abgeschnitten und grenzt dort tektonisch an mittelgrauen, undeutlich gebankten, lagunären Waxeneckdolomit. Bereits ca. 400m vor diesem Kontakt werden die Kalke der Aflenz-Formation deutlich heller und enthalten gradierte Schuttlagen. Im Bereich des Höchstein 1741 m geht die Aflenz-Formation schließlich in gebankten Dachsteinkalk in Vorriff-Fazies über. Aufgrund von Conodontendaten kann die Aflenz-Formation im Raum Aflenz in das höhere Norium (Sevatium) eingestuft werden. Außerhalb des Arbeitsgebietes folgen im stratigraphisch Hangenden der Aflenz-Formation mergelige Zlambachschichten des Rhaetiums.

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Die Magnesitlagerstätten von Oberdorf an der Laming

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Österreich war am Ende des 19. Jahrhunderts und bis weit hinein in das 20. Jahrhundert weltweit federführend in der Nutzung von Magnesit. Dies spiegelt sich auch in der Nomenklatur der wirtschaftlich wichtigsten Magnesitlagerstättentypen wider. In der wissenschaftlichen Literatur wird die Lagerstätte Veitsch für Spatmagnesit und für kryptokristallinen Magnesit die Lagerstätte Kraubath als Typlokalität verwendet (REDLICH, 1907). Während kryptokristalline Magnesite hauptsächlich an Ophiolithe gebunden sind, befinden sich Spatmagnesitlagerstätten stets in dolomitischen und/oder kalzitischen Nebengesteinen. In Österreich wurden bisher mehr als 50 Magnesitvorkommen entdeckt. Der Großteil liegt in der Grauwackenzone (GWZ). Sieben Lagerstätten stehen derzeit noch in Abbau (Abb. 1).

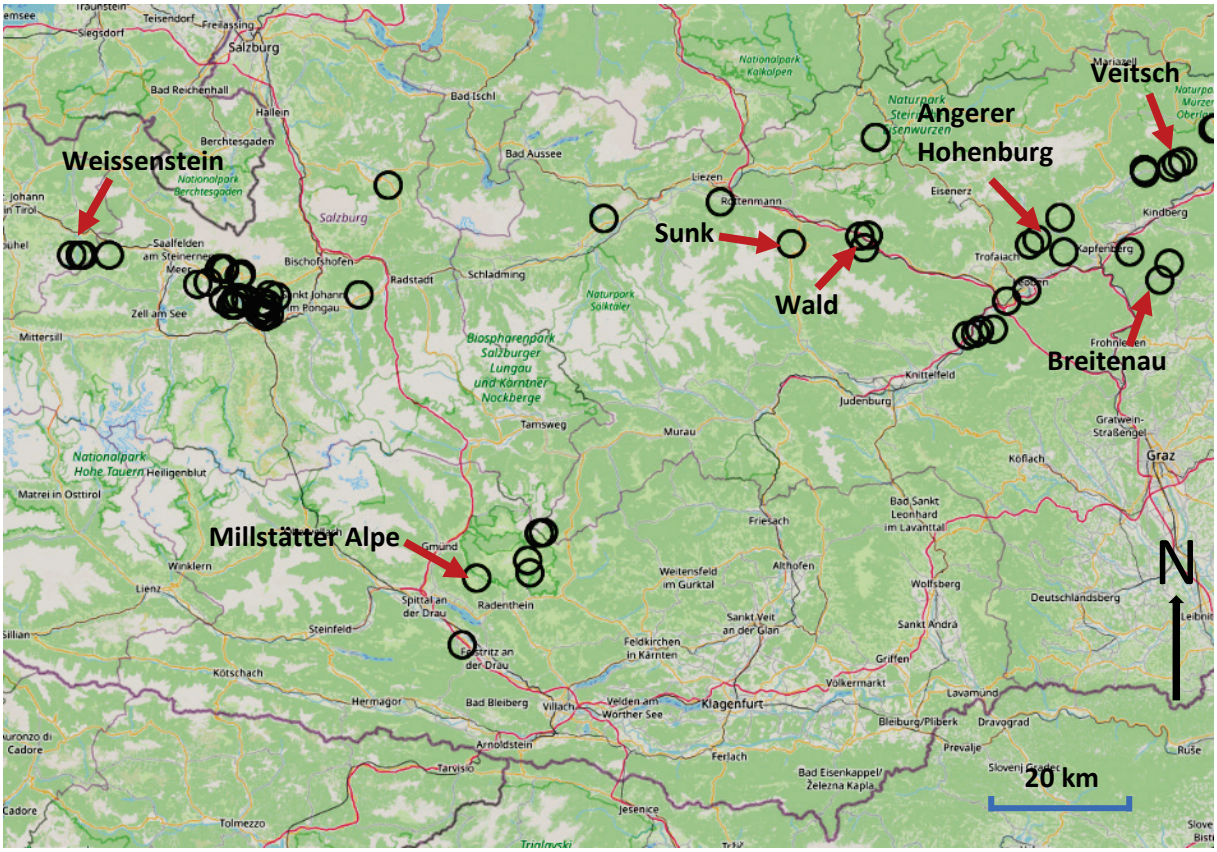

Abb. 1. Magnesitlagerstätten und aktive Magnesitbergbaue in Österreich. Die Abbaue Weissenstein, Millstätter Alpe und Breitenau werden von RHI Magnesita GmbH, Wald am Schoberpass, Sunk, Angerer und Hohenburg von Styromag GmbH, Veitsch von Rohrdorfer Baustoffe Austria GmbH betrieben (www.openstreetmap.org, https://iris.geologie.ac.at; 25. Juli 2022).

Charakteristisch für Spatlagerstätten vom Typ Veitsch in der östlichen GWZ ist, dass die Vorkommen in karbonen (Visé), flachmarinen, fossilführenden Karbonatgesteinen stratiforme Lagen, Linsen und irreguläre Magnesitkörper bilden. Sie sind grobkristallin, gebändert und teilweise pinolitisch. Die Matrix zwischen den Magnesitkristallen ist grau bis schwarz, feinkristallin und enthält fein verteiltes organisches (semigraphitisches) Material. Als direktes Nebengestein tritt Dolomit auf. Nach der Magnesitbildung folgen oftmals mehrere Generationen von Dolomit; hervorzuheben sind der

Magnesitbildung direkt nachfolgend gebildete grobkristalline Rosszahndolomite. Chlorit- (Leuchtenbergit) und Talkanreicherungen sind an Störungs- und Randzonen der Magnesitkörper gebunden. Talk wurde aus solchen Lagerstätten auch bergmännisch gewonnen (z.B. Lassing). Zusätzlich kann oft eine spätere Redolomitisierung des Magnesits entlang von Störungen beobachtet werden. Sporadisch auftretende Sulfidmineralisationen im Magnesit mit Fahlerz, Kupferkies, Pyrit und manchmal auch Gold stehen ebenso wie die Talklagerstättenbildung nicht im zeitlichen Zusammenhang mit der Magnesitgenese. Die Magnesitlagerstätten der GWZ wurden in der Kreide grünschieferfaziell metamorph überprägt.

Seit Mitte des 19. Jahrhunderts wurden unterschiedliche genetische Modelle der Spatmagnesitlagerstätten entwickelt. Sowohl syngenetische, frühdiagenetische als auch epigenetische Modelle wurden vielfach beschrieben (z.B. RUMPF, 1873; KOCH, 1893; REDLICH, 1907; LEITMEIER, 1917; PETRASCHECK, 1932; DE LLARENA, 1953; LEITMEIER & SIEGL, 1954; NIEDERMAYR et al., 1989; PROCHASKA, 1999). Zusammenfassungen der vorhandenen Literatur wurden mehrfach publiziert (z.B. POHL & SIEGL, 1986; MÖLLER, 1989). Zusammenhänge zwischen der Bildung von Magnesit- und Sideritlagerstätten in den Alpen wurden ebenfalls postuliert (REDLICH, 1907; PETRASCHECK, 1932; PROCHASKA, 1999).

Das jüngste genetische Modell beschreibt eine epigenetische Bildung (PROCHASKA, 1999, 2000a, b; Abb. 2): Im Gelände sind stets metasomatische Gefüge zu beobachten, die auf hydrothermale Lösungen zurückzuführen sind. Im Gegensatz zu früheren Beschreibungen sind eindeutig sedimentäre Anreicherungen von Mg in Form von Magnesit bislang nicht gefunden worden. Durch die chemische Analyse von Flüssigkeitseinschlüssen und Crush-Leach-Analysendaten (Br, Cl, I, Na, Mg, K, SO_4) wird darauf geschlossen, dass für die Lagerstättenbildung in geringer Tiefe evaporitische Lösungen mit hohem Mg/Fe-Verhältnis vorhanden waren. Die Lagerstättenbildung erfolgte postvariszisch sowie präkretazisch bzw. vor der alpidischen Orogenese. Generell seien die Magnesitkörper weder schichtgebunden noch schichtförmig. Es wird angenommen, dass im Permoskyth durch Rifting Wegigkeiten entlang von Störungen für evaporitische Lösungen geschaffen wurden, die in geringeren Tiefen Magnesit entstehen ließen. In größeren Tiefen wurden diese basischen Lösungen in saure hochsalinare Wässer umgewandelt, die Eisen in größeren Mengen lösen konnten und in weiter Folge Sideritlagerstätten bildeten.

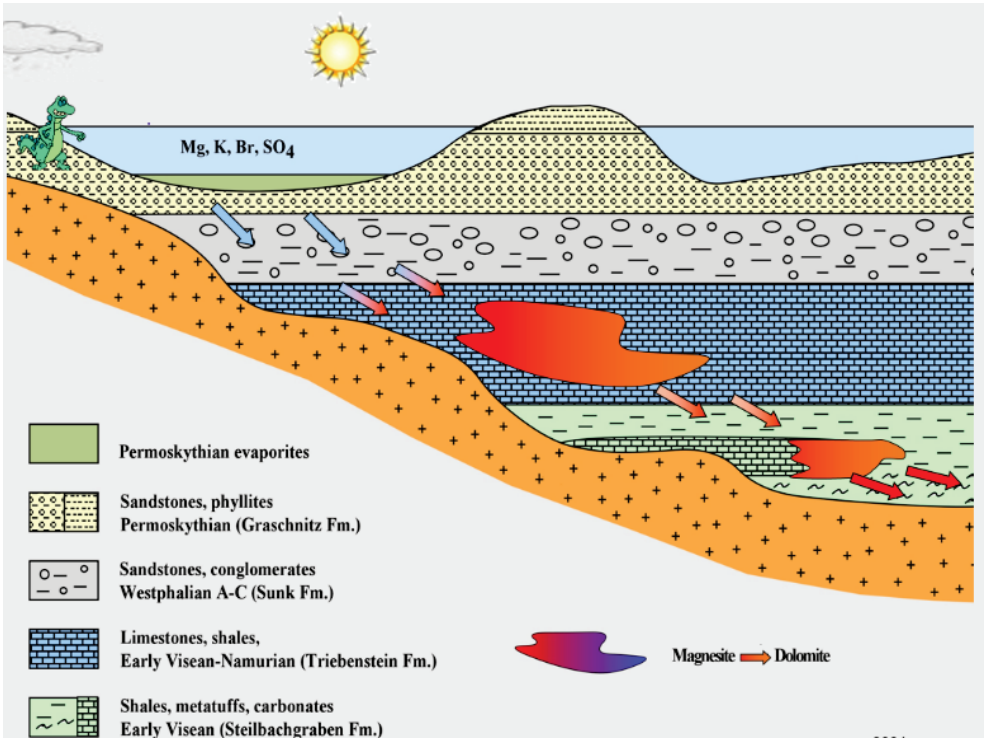

Abb. 2. Genetisches Lagerstättenmodell für die Magnesitlagerstätten der östlichen Grauwackenzone (PROCHASKA, 1999, 2000a, b).

Die Magnesitlagerstätten Wieser, Angerer und Hohenburg bei Oberdorf an der Laming liegen ca. 8 km nördlich von Leoben. In der näheren Umgebung wurden auch noch kleinere Magnesitvorkommen dokumentiert, die jedoch nie von wirtschaftlicher Bedeutung waren (z.B. Tulleralm, Abb. 3, LESKO, 1960). Im Liegenden der lagerstättenführenden Veitsch-Decke befindet sich das amphibolitfaziell geprägte Kletschachkristallin, das aus Gneisen, Amphiboliten, Migmatiten, Apliten und Pegmatiten besteht. Die Abgrenzung zur hangenden Veitsch-Decke wird durch Quarzite, Rauhwacken sowie Kalk- und Dolomitschollen gebildet (Abb. 4). Über dem Kletschachkristallin liegen Triaskalkschuppen und permoskythische Konglomerate und Sandsteine der Rannach Formation. Darüber setzen die graphitischen Schiefer und Phyllite des Unterkarbons der Veitsch-Decke ein, welche von dünnplattigen Kalken, Dolomiten und Magnesiten überlagert werden (Abb. 5). Die maximale Mächtigkeit der Karbonate beträgt weniger als 100 m, wobei die Magnesitmächtigkeit bis zu ca. 60 m erreichen kann.

An der Hangendgrenze und auch innerhalb der Lagerstätte treten sporadisch Grünschiefer auf, die als Tuffabkömmlinge interpretiert werden. Über den Magnesiten folgen wieder feinklastische und Graphit führende Phyllite und Schiefer mit geringmächtigen Kalkeinschaltungen. Die Veitsch-Decke wird im Hangenden von den höhermetamorphen Gesteinen der Kaintaleck Decke oder der Norischen Überschiebung begrenzt. Der Internbau des Karbons ist durch Falten und Schuppungen charakterisiert, wobei in der Umgebung der Lagerstätte ein generelles mittelsteiles Einfallen nach NW und flache NE–SW verlaufende Faltenachsen vorliegen. Die Lagerstättenkörper sind von vielen Störungen durchsetzt und vielerorts auch durch Störungen begrenzt.

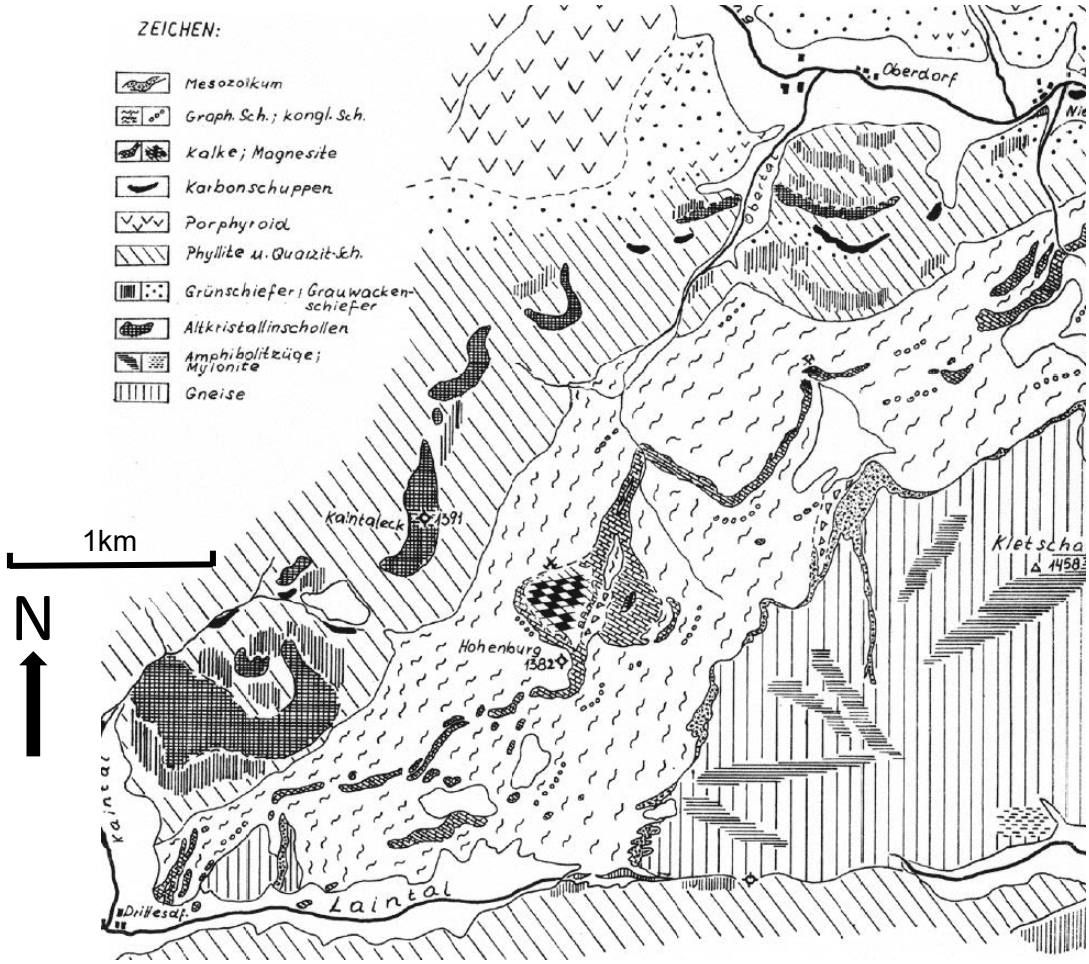

Abb. 3. Geologische Karte zwischen Oberdorf und Laintal (LESKO, 1960).

Neben den Karbonaten treten in der Lagerstätte Talk, Apatit, Aragonit, Baryt, Coelestin, Epsomit, Fahlerz, Gips, Kupferkies, Leuchtenbergit, Markasit, Pyrit, Palygorskit, Quarz (Rauchquarz, Amethyst), Chalcedon und Strontianit auf. Insbesondere sind die bis zu 10 cm großen verzwilligten idiomorphen Pyrite und die bis zu 12 cm großen Strontianitkristalle unter den Mineraliensammlern sehr begehrt.

In den Magnesitlagerstätten bei Oberdorf finden sich insbesondere entlang von Störungen auch größere Talkkörper. Auch an der Hangendgrenze des Magnesits wurden in Hohenburg, Wieser und Angerer Mitte des 19. Jahrhunderts großflächig vertalkte Zonen mit bis zu mehreren Metern Mächtigkeit untertage abgebaut (HADITSCH, 1966). Die untertägigen Teile des Bergbaues Wieser sowie Angerer sind jedoch nicht mehr zugänglich und im Bergbau Hohenburg sind im Zuge des fortschreitenden Magnesitbergbaues alle Spuren des Talkbergbaues verschwunden. Der Talk ist weiß, selten rosarot, grünlich, aber auch dunkelgrün, wenn er mit Leuchtenbergit verwachsen ist. In den oberflächennahen Bereichen ist er zumeist wegen der Verwitterung des enthaltenen Pyrits braun gefärbt.

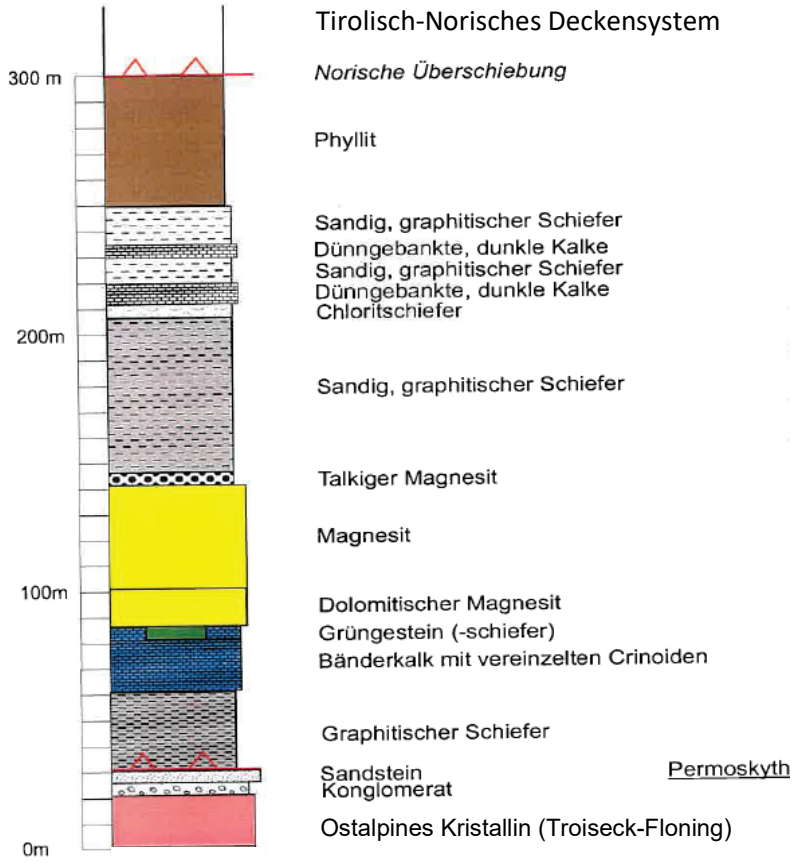

Abb. 4. Schematisches Säulenprofil der Veitsch-Decke in der Umgebung der Magnesitlagerstätte Oberdorf an der Laming (modifiziert nach TROBY, 2001).

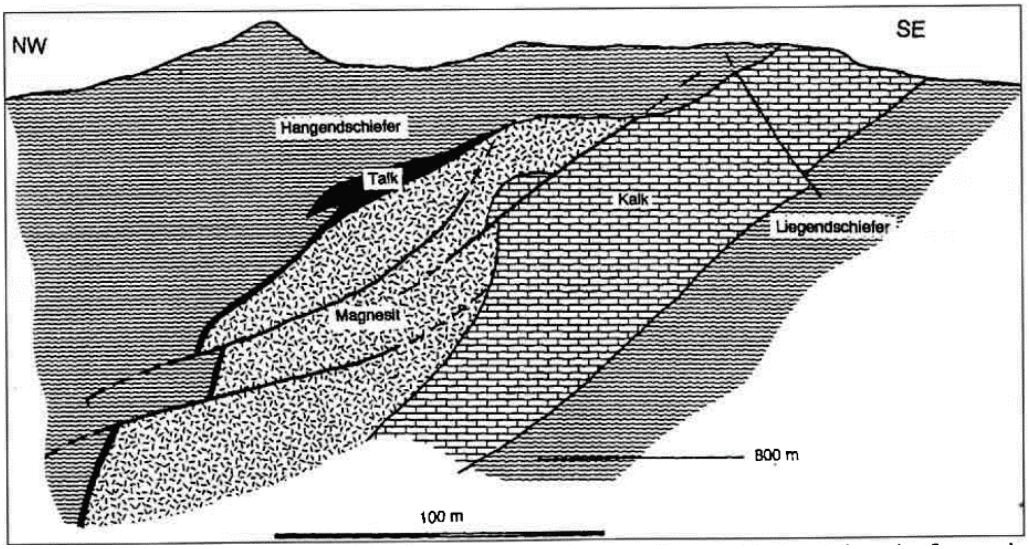

Abb. 5. Geologischer Schnitt durch die Magnesitlagerstätte Oberdorf an der Laming (HIESSLEITNER, 1952).

Derzeit werden die Magnesitlagerstätten bei Oberdorf, Wald am Schoberpass und auch Sunk bei Trieben von der Firma STYROMAG GmbH abgebaut (Alleingesellschafter Dr. Ernst H. Stefan, Bergbaubetriebsleiter DI Philip Kroissenbrunner). Die Jahresproduktion aus all diesen Bergbauen beträgt insgesamt ca. 120.000 t Rohstein. Die wesentlichen chemischen Qualitätskriterien für unterschiedliche Verwendungen betreffen die Mg-, Ca-, Si- und Fe-Gehalte im Rohstein. In Oberdorf wird im Etagenofen bei 790 °C kaustisch gebranntes MgO erzeugt. Einsatzgebiete für kaustisch gebranntes MgO sind Industriefußböden, Schleifsteine, Bremsbeläge, Düngemittel, Futtermittel, Zellstoffherstellung, Brandschutz, Kläranlagen sowie Bindemittel für Bergbauversatz. Rohstein findet Verwendung in der Eisen- und Stahlerzeugung.

Exkursionsstop 1. Tagebau Hohenburg

Die Magnesitlagerstätte wurde auf sieben Etagen durch Bohr- und Sprengarbeit bergmännisch aufgefahren (Abb. 6).

Abb. 6. Tagbau Hohenburg der STYROMAG GmbH (Foto: P. Kroissenbrunner, 2022).

An der Westseite des Tagebaues ist der liegende feinkristalline Dolomitmarmor aufgeschlossen. Im Übergangsbereich zum Pinolitmagnesit wurden weiß-grau gebänderte Zebradolomite angetroffen, zusätzlich finden sich hier vermehrt grobkristalline Rosszähne aus Dolomit, die in der Endphase der Magnesitbildung entstanden sind. Rosszähne treten jedoch auch innerhalb des Magnesits auf. Feinkristalliner Talk umrandet einerseits die groben Magnesitkristalle, andererseits füllt er mehrere Dezimeter mächtige Scherzonen, wo auch Millimeter bis Zentimeter messende Pyritkristalle gefunden wurden. In der Lagerstätte wurden mancherorts durch kieselsäurereiche Fluide gebildete Pseudomorphosen von Talk nach Magnesit gefunden, welche noch das ehemalige pinolitische Gefüge des Spatmagnesits abbilden ($3\ MgCO_3 + 4\ SiO_2 + H_2O \rightarrow Mg_3Si_4O_{10}(OH)_2 + 3\ CO_2$). Im zentralen Teil des Tagbaues stehen braune, leuchtenbergit- und leukoxenreiche Talke an, die als hydrothermal umgewandelte ehemalige Grünschiefer angesehen werden.

Exkursionsstop 2. Tagebau Angerer

Im höchsten Teil des Tagebau Angerer (Abb. 7) sind hangende Graphitphyllite bis Graphit führende Metasandsteine aufgeschlossen.

Abb. 7. Tagbau Angerer der STYROMAG GmbH. Die ehemaligen Abbaukammern des Untertagebaues kommen durch die Erweiterung des Tagebaues an das Tageslicht (Foto: P. Kroissenbrunner, 2022).

In unmittelbarer Nähe der Magnesitlagerstätte gehen sie in grobe, mehrere Meter mächtige Quarzkonglomerate über, die zum Teil sehr stark zu Talk umgewandelt wurden. Heller, grünlicher bis weißer Talk findet sich auch in den Störungen im Magnesit. Im Unterschied zu Hohenburg ist der Magnesit etwas gröberkristallin und zumeist hellgrau bis weiß. Im Bergbau Angerer wird der eisenärmste Magnesit aller österreichischen Spatmagnesitlagerstätten abgebaut. Er wird daher u.a. für die Herstellung von Sorelzement genutzt.

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The Weinebene pegmatite deposit

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1. Spodumene pegmatite deposits of Austria

In the Austroalpine basement about 80 spodumene ($LiAlSi_2O_6$) bearing pegmatites of Permian age are known (Fig. 1). The most prominent occurrence in Austria is the Weinebene deposit located at Koralpe in the South of Austria. Other occurrences were discovered in the areas near Haslau, St. Radegund, Übelbach, Katzbachgraben, Altes Almhaus, Wildbachgraben, Klementkogel, Hüttenberg, Falkenberg, Wölz Tauern, Millstatt Seerücken, Wöllatratten, and Defereggen valley. The Koralpe-Wölz Nappe-system hosts spodumene pegmatites in Southern Tyrol near Ratschinges and Lenkstein (KNOLL et al., 2018). Pegmatites in the Austroalpine basement, which formed during the Variscan or Eo-Alpine orogeny, do not contain any lithium mineralization.

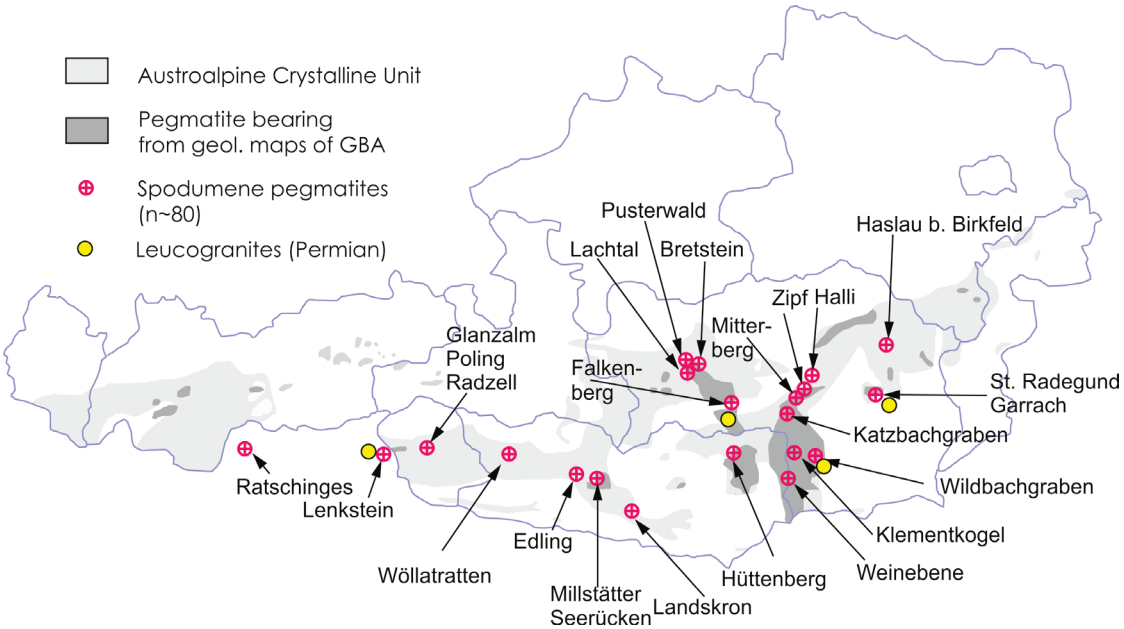

Fig. 1. Permian spodumene pegmatite and leucogranite occurrences in the Eastern Alps.

Permian pegmatites occur at different paleo-crustal levels between c. 23 km and 10 km depth. They formed at temperatures and pressures between 600–700 °C and 6–7 kbar, respectively (Fig. 2). The deepest level host rocks comprising paragneisses and micaschists show migmatitic structures and are supposed to be the source for the initial anatectic pegmatitic melt. Irregular patches of pegmatitic neosome, sometimes gradational to the host contain fine to coarse feldspar and muscovite porphyroblasts. These patches converge to pegmatite networks as well as to thin barren, concordant or discordant pegmatite dykes. At medium depths concordant, non-zoned, and barren pegmatites intruded mainly into staurolite or kyanite (paramorphs of Permian andalusite) bearing host rocks. Sometimes Permian leucogranite bodies of a few hundred meters in thickness are associated with the pegmatites. The shallowest levels embody zoned, concordant, as well as discordant pegmatite dykes that are highest evolved and spodumene bearing in some places. Spodumene pegmatites are hosted by micaschists, paragneisses, amphibolites and marbles.

Usually the mineralogical composition of the pegmatites is rather simple with albite, K-feldspar, quartz and muscovite. Tourmaline, zircon, xenotime, monazite, garnet, and biotite are present in many pegmatites. Beryl, apatite, Nb-Ta-minerals, cassiterite, Nb-rutile and other accessories are rather rare. In spodumene pegmatites, the spodumene contents are highly variable ranging from 0.1 vol.-% up to 30 vol.-%. Exocontact alteration results often in silicification and tourmalinization. In amphibolite host rocks additional growth of biotite could be observed.

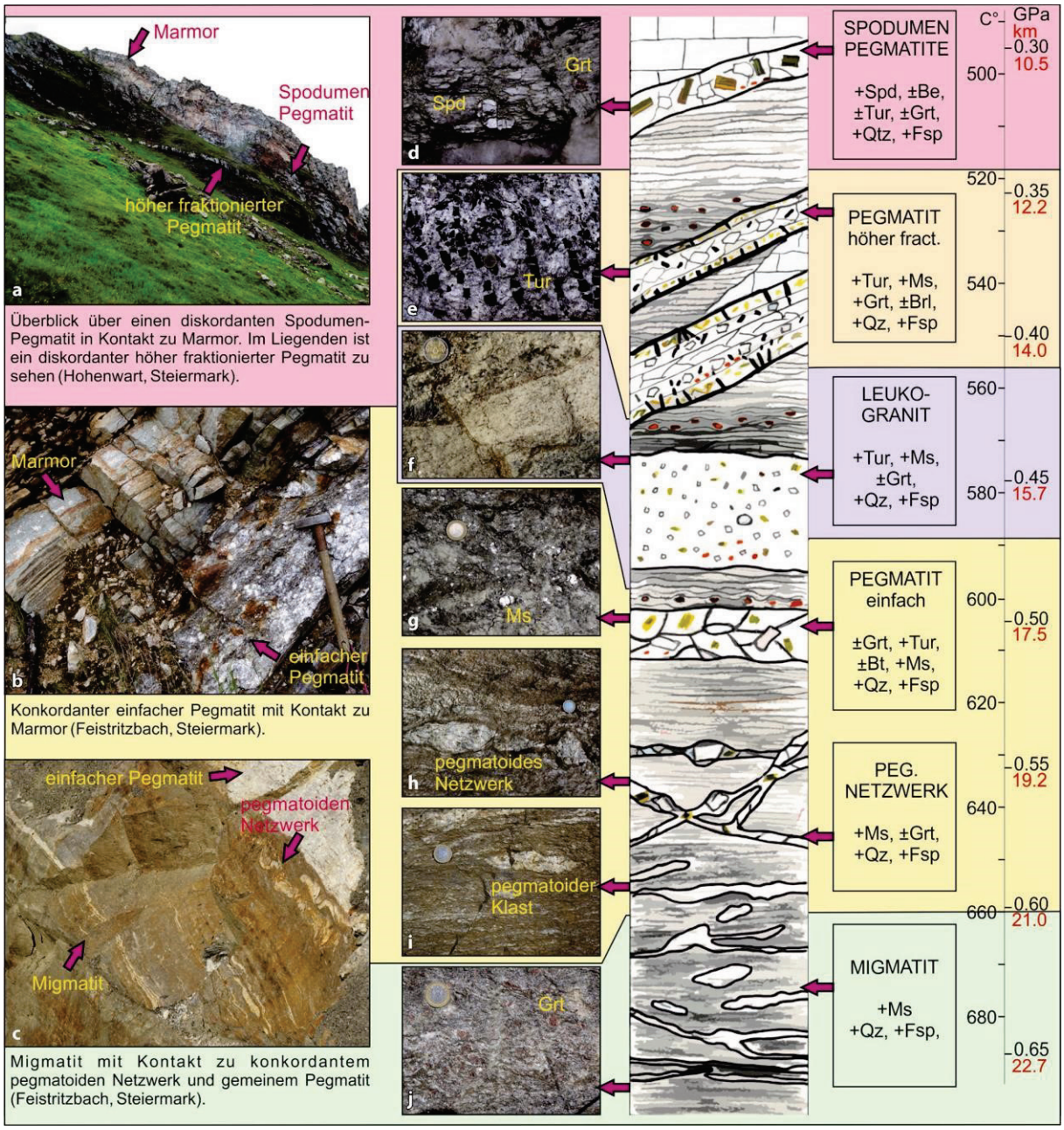

Fig. 2. Synoptic diagram showing field relations for Permian pegmatites and leucogranites in the Austroalpine unit of the Eastern Alps. Three domains (green, yellow and reddish) are distinguished (see text). Outcrop pictures of a) spodumene pegmatite, b) concordant barren pegmatite and c) migmatitic mica schist with pegmatitic networks and dykes. Compilation of typical lithologies: d) spodumene pegmatite (width of image 7 cm), e) comb structures of deformed tourmaline (width of image 37 cm), f) inhomogeneous leucogranite (width of image 20 cm), g) muscovite pegmatite (width of image 25 cm), h) deformed pegmatitic network (width of image 40 cm), i) pegmatitic patches within deformed migmatitic mica schist (width of image 30 cm), j) garnet-rich restitic paragneiss (width of image 20 cm). k) Schematic column showing the distribution of typical lithologies, magmatic assemblages and depth-pressure-temperature relations (KNOLL et al., 2021).

Whole rock geochemistry shows high contents of Si, Al, K and Na. Li_2O contents of spodumene pegmatite specimens reach ca. 2.5 wt.-% at maximum (Tab. 1). Nb and Ta contents are below 100 ppm, and Be and Sn are also below economic importance. Quartz and feldspars are suitable for glass and ceramics production due to the low Fe content.

		Zinkenschlucht	Scharnitzfeld	Weittal	untere Mittagswand	Hohenwart Südwand	Hohenwart Südwand	Edling	Weinebene Amphibolites	Weinebene Micaschist	Rieserferner
SiO_2	g/100g	73.76	73.64	73.95	65.21	72.07	70.62	73.20	74.10	74.78	76.36
TiO_2	g/100g	0.02	0.01	0.01	0.00	0.05	0.00	0.02	0.02	0.03	<dl
Al_2O_3	g/100g	16.53	16.35	15.38	22.39	17.88	18.00	18.00	15.75	15.49	15.14
FeO	g/100g	0.45	0.39	0.12	0.45	0.08	0.24	0.24	0.62	0.59	0.49
MnO	g/100g	0.14	0.11	0.08	0.15	0.13	0.05	0.01	0.08	0.06	0.06
MgO	g/100g	0.04	0.03	0.06	0.24	0.10	0.02	0.08	0.09	0.06	<dl
CaO	g/100g	0.34	0.27	0.29	0.65	0.95	0.42	0.06	0.36	0.30	0.17
Na_2O	g/100g	3.99	4.31	3.15	6.11	4.61	5.94	2.86	2.84	3.40	4.12
K_2O	g/100g	2.74	2.78	3.68	2.42	1.35	2.72	2.56	2.71	2.43	1.20
P_2O_5	g/100g	0.08	0.10	0.06	0.08	0.02	0.10	0.09	0.38	0.41	<0.01
Li_2O	g/100g	0.98	1.49	2.46	0.76	1.55	1.01	2.13	2.22	1.28	1.62
LOI	g/100g	0.82	0.82	0.82	1.59	0.42	0.56	0.80	0.51	0.78	0.59
SUM	g/100g	99.89	100.30	100.06	100.05	99.21	99.68	100.05	99.68	99.61	99.75
Pb	mg/kg	34	38	49	46	45	61	129			
Zn	mg/kg	16	17	13	35	26	66	108			
Sn	mg/kg	43	39	25	14		24		138	85	
Rb	mg/kg	401	433	706	310	247	395	350	1108	878	
Cs	mg/kg	85	20	99	28		44	16	62	25	
Ba	mg/kg	49	45	50	78	17	15	13			
Sr	mg/kg	37	33	158	49	31	22	9			
Ga	mg/kg	26	31	22	31		24				
Ta	mg/kg	15	30	51	14		3		19	24	
Nb	mg/kg	30	79	86	28	104	17		55	85	
Th	mg/kg	2	1			10	1				
U	mg/kg	8	5	2			2		6	9	
Y	mg/kg	12	6	10	8	16					
La	mg/kg	2	2		2		2				
Ce	mg/kg	5	4								
Sm	mg/kg	1	1.1	0.1	0.6		0.9				
Yb	mg/kg	0.5	0.5		0.4		0.4				
Be	mg/kg	83	99	49	42	223	52	190	59	54	
Zr	mg/kg	55	23	15	19	28	35				
Hf	mg/kg	1.9	1.6	1.3	0.9		0.7				

Tab. 1. Whole rock geochemistry of selected spodumene pegmatites (GÖD, 1989; LUECKE & UCIK, 1986; MALI, 2004; PROCHASKA, 1981).

To determine the fractionation degree, more than one thousand magmatic muscovites of host rocks, pegmatites, and leucogranites were analyzed by Laser Ablation ICP-MS (Fig. 3, CERNY 1982). In the course of fractionated crystallisation along the intrusion path of the pegmatite melt, trace elements like Li, Rb, Cs, Tl, Ga, Hf, Nb, Ta become enriched, whereas Ba and Sr are depleted. K/Rb in muscovite is a good indicator for the degree of fractionation. Muscovites of the spodumene pegmatites show K/Rb ratios < 100. Muscovite analyses of many barren pegmatites demonstrate comparable K/Rb ratios, indicating promising areas of rare element pegmatites (Fig. 4). Breakdown of staurolite and/or muscovite during anatectic melt formation is probably the source of Li. Significant enrichment of Li up to 7000 mg/kg in the melt through crystal fractionation may result in spodumene crystallization (LONDON, 2008).

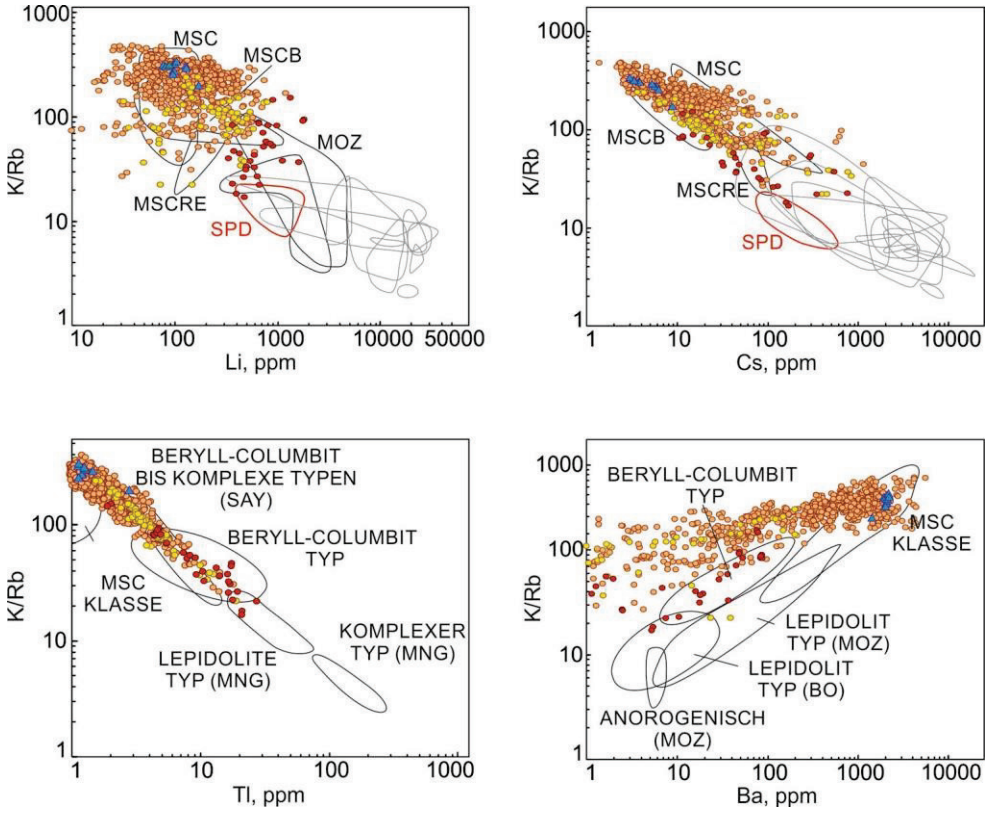

Fig. 3. Trace element composition of Permian muscovites in migmatites (blue dots), low to highly evolved pegmatites (orange dots), leucogranites (yellow dots) and spodumene pegmatites (red dots, classification after CERNY, 1982; KNOLL et al., 2021).

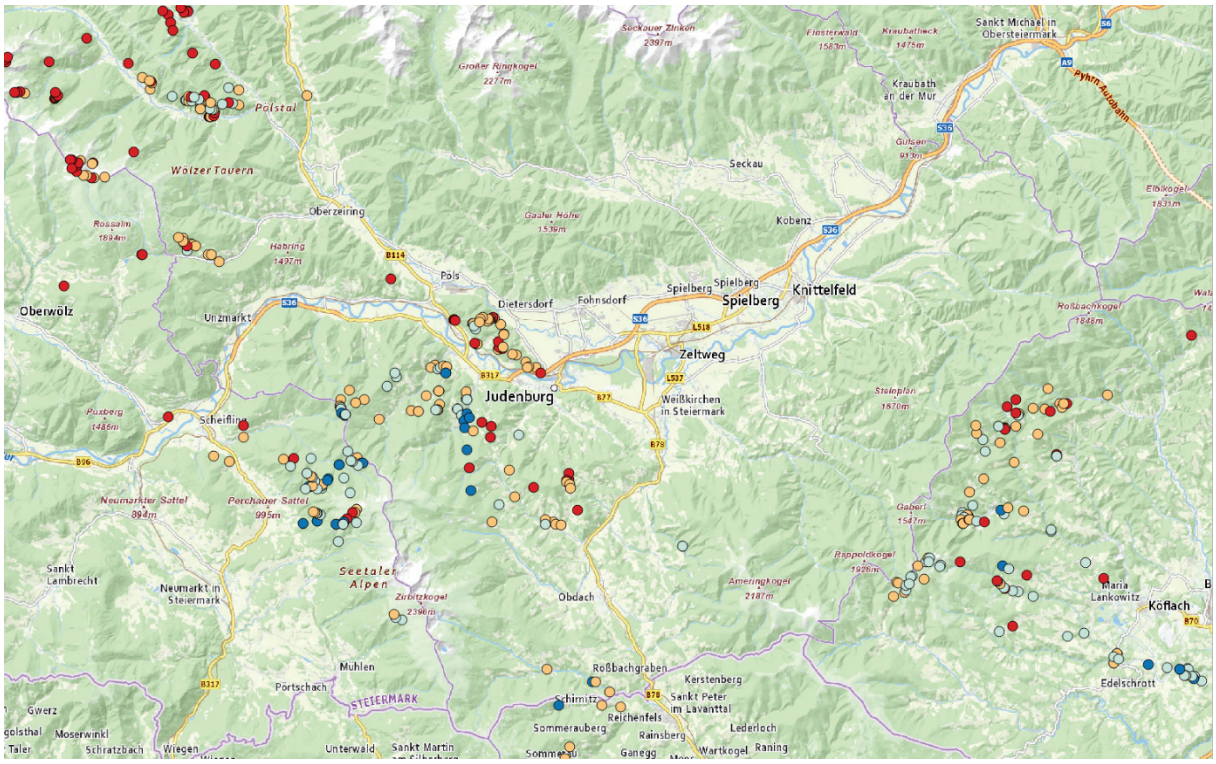

Fig. 4. K/Rb ratio of muscovite from Permian pegmatites in Styria (red 20–100, orange 101–200, green 201–300, blue > 300). Red dots indicate potential areas of spodumene pegmatite occurrences.

2. The Weinebene pegmatite deposit

Spodumene was discovered at the Weinebene about 80 years ago (MEIXNER, 1966). In 1981, Minerex, a former Austrian government company, started extensive exploration resulting in underground test mining and a pre-feasibility study in 1987. In 1988, the project was transferred to the Bleiberger Bergwerksunion mining company. 1991, the project was sold to Kärntner Montanindustrie, operating a hematite mine at Waldenstein, to secure the access to the spodumene deposit and the test mine, respectively. In 2011, Global Strategic Metals and Exchange Minerals acquired the project for € 9.7 mio plus 20 % VAT (europeanlithium.com; 13th July 2022).

The deposit is located in the Koralpe-Wölz Nappe-system of the Austroalpine basement. Host rocks are amphibolites and micaschists forming a Cretaceous anticline with a fold axis plunging to the East (Fig. 5). The amphibolites are composed of amphibole, plagioclase, few garnet, subordinate quartz as well as calcite. The micaschists comprise muscovite, quartz, garnet, biotite and plagioclase. Kyanite paramorphs after andalusite are also present. In total 15 spodumene pegmatite dykes were discovered with a persistence of up to 1500 m and with variable true thicknesses of 10 m at maximum. The amphibolite hosted pegmatites are rather coarse crystalline in contrast to the micaschist hosted pegmatites. The latter ones are classified as mylonitic spodumene pegmatite gneisses due to intense ductile deformation and recrystallization during the Alpine orogenic event. The mineral assemblage includes spodumene, quartz, albite, microcline, muscovite, beryl, black tourmaline, apatite, graphite, cassiterite, triphylite, ferrisicklerite, microlite and zircon, among a great variety of secondary minerals. The deposit is also the type locality of weinebeneite ($CaBe_3(OH)_2(PO_4)_2.4H_2O$; WALTER et al., 1990; NIEDERMAYR & GÖD, 1992).

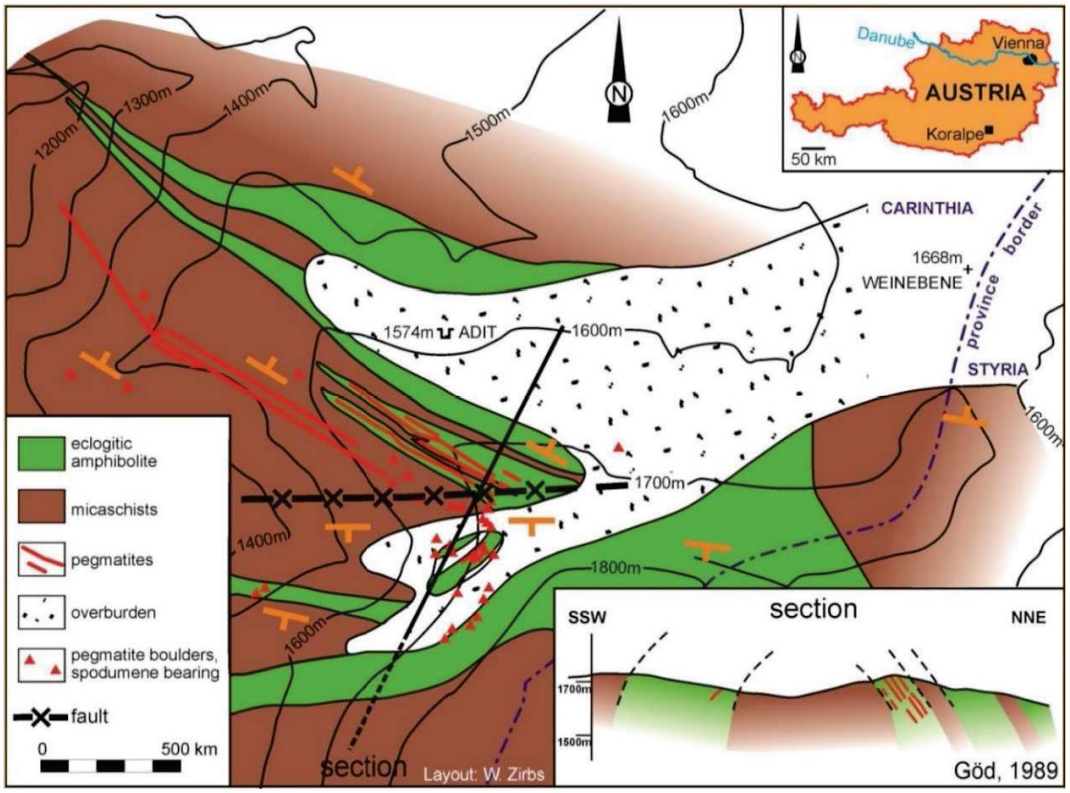

Fig. 5. Cross section of the Weinebene spodumene deposit anticline, dividing the deposit in a northern and a southern limb (GÖD, 1989).

Four decades ago, Minerex started to explore the deposit via drillings and underground test mining (Fig. 6). Since 2011, subsequent drillings were made and more than 1000 t of ore were mined for processing tests. Currently, the project is operated by European Lithium LTD, listed at Australian and European stock exchanges. In total, about 30 km of drill cores were recovered and analyzed. Based on these data, a 3D deposit model was generated for resource calculation, grade distribution and mine design. The pre-feasibility study reports JORC compliant ore resources (measured, indicated and inferred) of more than 12 mio t, grading ca. 1.0 wt.-% Li_2O. 2022, the company released an interim definitive feasibility study (DFS) update announcement on the major DFS key performance indicators including the pre-tax net present value for the accelerated case of A$ 862 million, a maximum of 20 years lifetime of the spodumene pegmatite mine with an annual ore production of approximately 770,000 t (ASX Announcement, 19th April 2022, europeanlithium.com). At full production, this results in an annual output of ca. 11,000 t LCE (Lithiumcarbonate Equivalent, europeanlithium.com, 13th July 2022).

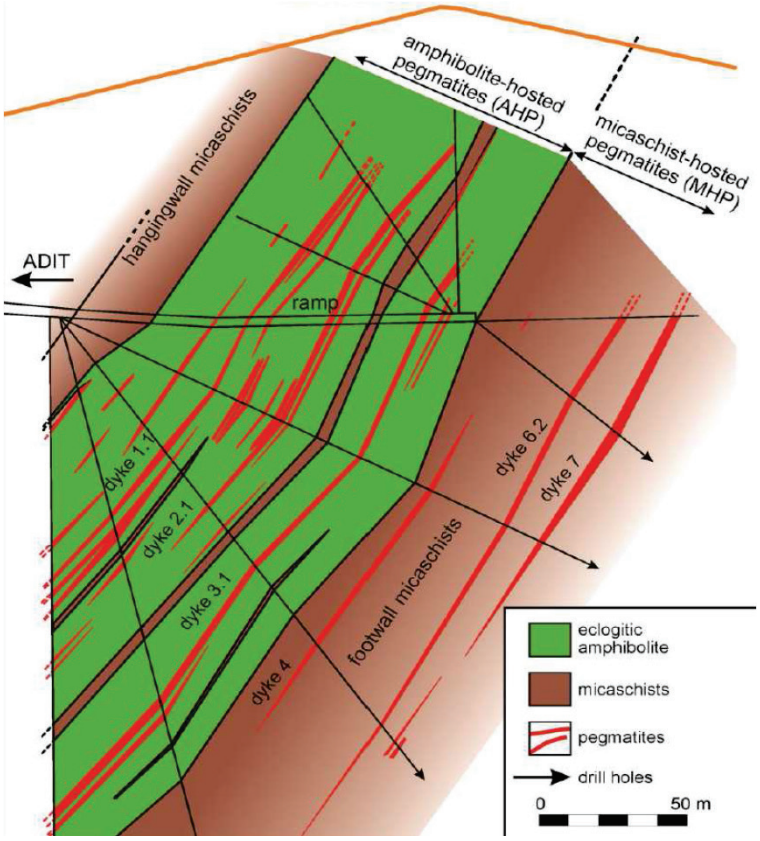

Fig. 6. Geological cross section and test mine drifts of the Weinebene deposit (GÖD, 1989).

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