

Magmatic-hydrothermal versus metamorphogenic origin of tungsten mineralization: Examples from the Eastern Alps

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The increasing demand for tungsten in the European high-tech industry is offset by an increased supply risk. Hence, this metal has been on the list of critical raw materials for the EU since 2011. Global tungsten production is primarily from ore deposit types genetically related to granitic intrusions (e.g., skarn-type, vein-type, porphyry deposits etc.) and linked with magmatic-hydrothermal processes.

Europe's largest tungsten mine is located at Felbertal in Austria in (pre-)Variscan units of the Tauern Window in the Eastern Alps. Recent studies also support a magmatic-hydrothermal model and re-interpreted the Felbertal deposit as a metamorphosed vein-stockwork scheelite deposit associated with chemically evolved, W-rich granitic melts emplaced during the Variscan orogeny (Kozlik & Raith 2017). In the Eastern Alps, however, there are still numerous smaller (sub-economic) tungsten showings that differ significantly from the Felbertal deposit in terms of their geological and mineralogical characteristics. Most of them lack a direct relation to igneous intrusions but occur proximal to large-scale tectonic structures in Paleozoic strata with metacarbonate rocks (e.g., Tux-Lanersbach, Mallnock) of the low-grade metamorphic Austroalpine units. Syngenetic/syndiagenetic sedimentary-exhalative models were suggested in the past but a metamorphogenic origin as discussed by Palmer et al. (2022) for the formation of this style of mineralization elsewhere is also plausible.

Scheelite (CaWO₄) is the most common tungsten mineral in the Eastern Alps and was analyzed by the combined use of cathodoluminescence, electron probe microanalysis and in-situ LA-ICP-MS analysis to determine the mineralogical-chemical signature of scheelite from different styles of tungsten mineralization. The combination of geological-mineralogical information and trace element analysis of scheelite allows to distinguish three generic mineralization styles in the Eastern Alps, i.e., 1) *intrusion-related*, 2) *polymetallic* (As, Sb, Au), and 3) *carbonate-hosted stratabound* scheelite mineralization. Mineral chemistry shows that the trace elements Na, Sr, Nb, Mo and REE+Y in particular are suitable for differentiating scheelites from these different ore forming environments.

We demonstrate that the “Felbertal” magmatic-hydrothermal signature of scheelite is distinctly different from other styles of mineralization and that these findings can be used as an indicator in future exploration to evaluate the regional tungsten potential.

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Palmer MC, Scanlan EJ, Scott JM, Farmer L, Pickering D, Wilson VJ, Oelze M, Craw D, le Roux PJ, Luo Y, Graham Pearson D, Reid MR, Stirling CH (2022): Distinct scheelite REE geochemistry and ⁸⁷Sr/⁸⁶Sr isotopes in proximally- and distally-sourced metamorphogenic hydrothermal systems, Otago Schist, New Zealand. - *Ore Geology Reviews* 144, 104800

The role of mineralogy: Case studies from Austr(al)ia

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The role and value of mineralogy in geosciences and material sciences have recently been hotly debated. In particular, the contribution of this long-established discipline in modern science and academic education has been questioned. So, what will mineralogy be focused on in the future, especially in the light of fundamental vs more applied perspectives? A closer look on mineralogy and the linked fields of crystallography, geochemistry and petrology, indicates interdisciplinary knowledge among the highly diverse fields of expertise to be key to an advanced process understanding in the various facets of human kind, climate change, resource scarcity, and technical challenges (Fig. 1).

In this contribution, various aspects of kinetic and equilibrium water-rock/mineral-gas interactions in low temperature settings are discussed, which are of high relevance for geo- and material scientist's present and future works. Focus is given on the assessment, identification and quantification of fundamental reaction mechanisms of mineral formation, dissolution, and transformation, tailoring/conditioning of (geo-)materials, and advanced understanding of the Earth system evolution throughout space and time. Case studies presented herein comprise of (i) carbonate vein infillings of vertical fractures (Erzberg), (ii) carbonation and external sulphate attack on concrete/shotcrete (Bosruck), (iii) (de)contamination/stabilization of soils using novel nZVI-bentonite nano-composites (Stadtschlaining), and (iv) environmental reconstruction of seawater chemistry by previously unrecognized archives (glauconites from the Arrowie and Amadeus basins, Australia). Recent advances in the analytical toolbox of mineralogists and (isotope) geochemists, such as in-situ Rb-Sr dating via LA-ICP-MS/MS, high-resolution optical imaging, and SEM-based automated mineral mapping, are highlighted, which offer new perspectives in geosciences and material sciences.

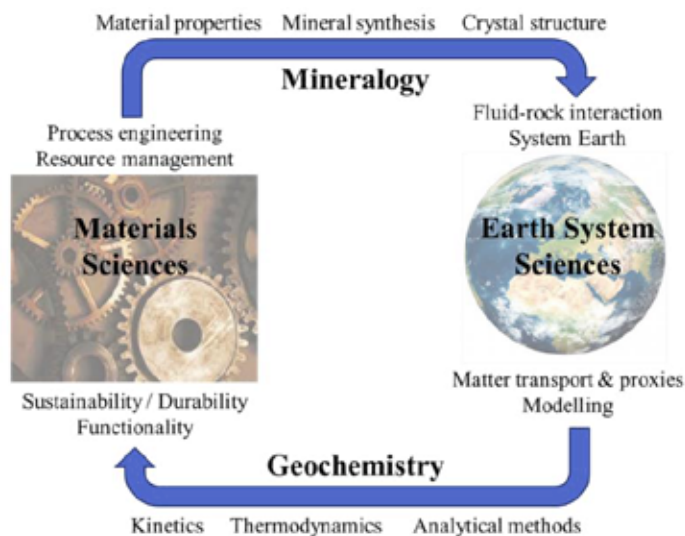


Figure 1. The role of mineralogy/geochemistry in geosciences and material sciences.

Structural diversity in new, synthetic zemannite-type phases

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The mineral zemannite (Matzat 1967; Fig. 1), named in honor of Prof. Josef Zemann (1923–2022), has a composition of $[\text{Zn}^{2+}\text{Fe}^{3+}(\text{TeO}_3)_3]_2[\text{Mg}(\text{H}_2\text{O})_6] \cdot n\text{H}_2\text{O}$ ($n \leq 3$), and is the mineral of the MinWien2023 conference. Synthetic zemannite-type phases can be obtained from hydrothermal reactions between transition metal oxides, tellurium dioxide and alkali metal carbonates. In comparison with the usual set-up for a hydrothermal experiment, the drastic reduction of the water content changes the role of water from a typical solvent to a mineralizer. Under these conditions, the formation of numerous new phases with zemannite-type structures was observed (Eder et al. 2023).

The crystal structures of the new zemannite-type phases were determined on basis of single-crystal X-ray diffraction. Like the mineral zemannite itself, the crystal structures of $\text{Fe}_2(\text{TeO}_3)_3$, $\text{Na}_2[\text{Ni}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{2.5}$, $\text{K}_2[\text{Ni}_2(\text{TeO}_3)_3](\text{H}_2\text{O})$, $\text{K}_2[\text{Zn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_2$, $\text{Rb}_{1.25}[\text{Co}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{1.5}$, $\text{Rb}_{1.24}[\text{Mn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_2$, and $\text{Na}_{1.79}\text{Mg}_{0.11}[\text{Mg}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{3.86}$ show hexagonal metrics, with $a \approx 9.3$ Å and $c \approx 7.7$ Å. Relative to this unit-cell, different kinds of superstructures are realized for $\text{Na}_2[\text{Cu}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{1.5}$ (threefold), $\text{K}_2[\text{Cu}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_2$ (twofold), $\text{K}_2[\text{Co}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{2.5}$ (twofold and incommensurately modulated), $\text{Rb}_{1.5}[\text{Mn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{1.25}$ (fourfold), and $\text{Cs}[\text{Mn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})$ (fourfold).

The formation of these superstructures can be attributed to several influences. Variable water contents (compounds with zemannite-type structures are known for their zeolitic properties (Miletich 1995)), the space requirements of large alkali metal cations like Rb^+ or Cs^+ , and Jahn–Teller distortions of the coordination polyhedra of certain framework atoms like Cu^{II} or Mn^{III} play crucial roles in this respect.

Another aspect of zemannite-type crystal structures is the nature and distribution of the contents inside the large hexagonal channels perforating the framework. For most of the investigated phases, alkali metal cations and crystal water molecules are displaced up to 2 Å from the channel center and are disordered around the 6_3 axis (or other symmetry elements containing a threefold rotation axis). In the superstructures of $\text{Rb}_{1.5}[\text{Mn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{1.25}$ and $\text{Cs}[\text{Mn}_2(\text{TeO}_3)_3](\text{H}_2\text{O})$, ordered channel-contents were observed. $\text{Fe}_2(\text{TeO}_3)_3$ has empty channels, which causes some Te^{IV} atoms of the framework to “tilt” towards the channel center. In $\text{Na}_{1.79}\text{Mg}_{0.11}[\text{Mg}_2(\text{TeO}_3)_3](\text{H}_2\text{O})_{3.86}$, both Na^+ and Mg^{2+} cations inhabit the channels together with H_2O molecules, and the superposition of their respective environments can be noticed in the crystal structure refinement.



Figure 1. Zemannite—the mineral of the meeting. Photo: S. Wolfsried

Eder F, Marsollier A, Weil M (2023): Structural studies on synthetic $A_{2-x}[\text{M}_2(\text{TeO}_3)_3] \cdot n\text{H}_2\text{O}$ phases ($A = \text{Na}, \text{K}, \text{Rb}, \text{Cs}$; $M = \text{Mn}, \text{Co}, \text{Ni}, \text{Cu}, \text{Zn}$) with zemannite-type structures. - Mineral Petrol <https://doi.org/10.1007/s00710-023-00814-5>

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Miletich R (1995): The synthetic microporous tellurites $\text{Na}_2[\text{M}_2(\text{TeO}_3)_3] \cdot 3\text{H}_2\text{O}$ ($M = \text{Zn}, \text{Co}$): crystal structure, de- and rehydration, and ion exchange properties. - Monatsh Chem 126, 417–430

The importance of volatiles in the formation of magmatic sulfide ore deposits: experimental constraints

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Research studies provide growing evidence for the presence of fluids within magmatic mineral systems of mafic-ultramafic composition, although these ore-forming magmas are generally considered as volatile-poor. Here we summarize the results of two experimental studies that clarify the role of volatiles in the formation of magmatic sulfide ore deposits in mafic-ultramafic magmas: (i) interaction experiments simulating magmatic assimilation of sulfate and/or organic compounds (Iacono-Marziano et al. 2017); (ii) a more recent experimental study shedding light on previously unnoticed physical processes ensuing from the association between sulfide melt and fluid phase (Iacono-Marziano et al. 2022). The silicate melt composition used for both studies is similar to the parental melt of the Noril'sk-Talnakh ore bearing intrusions in Polar Siberia and all materials used in the experiments were sampled from the Noril'sk region. Moreover, the experiments were conducted at magmatic conditions relevant to the emplacement pressures and temperatures of the Noril'sk-Talnakh intrusions, so that experimental findings are directly applicable to these world-class ores.

The addition of external sulfur to the magma is one of the most common ore-forming processes invoked for magmatic sulfide deposits. Sulphur can be introduced into the magma by several process, our experiments at magmatic conditions (1200 °C, 80 MPa) show that anhydrite assimilation in the presence of a reducing agent, i.e. organic matter-rich rocks such as coal, is extremely efficient in producing high sulfide supersaturation in the magma.

The association between the sulfide melt and the fluid phase has been shown to allow the upward transfer of the sulfide melt (Mungall et al. 2015). Our recent experimental results illustrate another physical process that occurs when the proportion of fluid phase in the magma is low: the sulfide-fluid association favors the accumulation of sulfide liquid by facilitating the coalescence of the sulfide droplets that are attached to the same fluid bubble. This leads to the accumulation of the sulfide melt in the upper part of the experimental samples. Coalescence of sulfide droplets may be facilitated by the lowering of their interfacial tension induced by the bubble. However, the main driver for coalescence to occur is likely to be the fact that connection to the bubbles keeps the droplets in contact for long enough to allow drainage of the melt film between them, as opposed to the situation in a flowing magma where adjacent droplets are sheared apart before the melt film has time to drain (Robertson et al. 2015). This process may enable sulfide droplets coalescence and deposition in flowing magma, which otherwise have been shown to be unlikely processes (Robertson et al. 2015).

Experimental results indicate that sulfur degassing to the fluid phase increases with increasing proportion of fluid phase, concurrently reducing sulfide melt stability. Consequently, the sulfide melt is consumed and its metal content augments. Experimental samples with increasing fluid contents present increasingly Ni- and Cu-rich sulfide melts, illustrating how metal enrichment of sulfide melt can be attained by sulfur degassing. Magma degassing can therefore lead to sulfide upgrading.

Extensive sulfur degassing may completely consume the sulfide melt and form platinum-group minerals (PGMs) at relatively high temperatures (1150 °C in our experiments). Platinum-group mineral formation in the experimental samples occurs by desulfurisation of the

sulfide melt, while Ni and Cu are partitioned between the silicate melt and the fluid phase. This suggests an unconventional mechanism of PGM formation at temperatures higher than those typical of sulfide melt crystallization.

The experimental results presented above illustrate how the occurrence of a fluid phase in a mafic-ultramafic magma may represent a significant boost for magmatic sulfide ore forming processes: sulfide melt accumulation, tenor increase, and crystallization of PGMs are indeed key processes in the formation of magmatic Ni-Cu-Co-PGE ore deposits. We use the world-class Noril'sk-Talnakh ore deposits, in Polar Siberia as a case study.

Noril'sk-Talnakh ores are hosted in mafic-ultramafic subvolcanic ribbon-shaped intrusions. Extensive interaction of the ore-forming magmas with evaporitic and carbonaceous rocks has been proposed to be at the origin of the mineralization and the coexisting abundant fluid phase (e.g. Iacono-Marziano et al. 2017). The three main ore types are described in ore-bearing intrusions: (i) massive sulfides in the lower part of the intrusion and largely in the country rocks; (ii) disseminated sulfides (also called globular ores) inside picritic and taxitic rocks, also in the lower part of the intrusion; (iii) low-sulfide PGE ores in the upper part of the intrusion (e.g. Le Vaillant et al. 2017; Schoneveld et al. 2020). In the second and third ore-types subspherical structures within the crystalline framework have been interpreted as fluid bubbles filled with late magmatic phases (segregation vesicles) and/or hydrothermal minerals (e.g. Le Vaillant et al. 2017; Schoneveld et al. 2020). In the lower part of the intrusion, these structures are systematically associated with sulfide minerals suggesting they represent sulfide-fluid associations preserved in the olivine-rich magmatic rocks (Le Vaillant et al. 2017). In the upper part of the intrusion, these subspherical structures are even more common, typically associated with oxide mineral coatings, and generally containing lower amounts of sulfide minerals but abundant PGMs (Schoneveld et al. 2020), suggesting higher extents of sulfur degassing and sulfide dissolution. In contrast, massive sulfides are proposed to have experienced low extents of sulfur degassing, attested by the lower metal contents with respect to disseminated sulfides.

The distribution of ore types in Noril'sk-Talnakh intrusions therefore strongly suggests an increasing extent of degassing toward the top of the intrusions, implying increasing sulfide melt consumption and metal enrichment. Several other magmatic sulfide ores present evidence of the occurrence of a fluid phase during ore formation (relevant information can be found in Iacono-Marziano et al. 2022). Although a role for volatiles is less clear in other deposits, an increasing number of examples of sulfide-fluid associations is reported, suggesting that the mechanisms illustrated by the experiments may be more common than currently considered. We conclude that the role of volatiles in the formation of magmatic sulfide deposits should probably be re-evaluated.

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Zemannite, $\text{Mg}(\text{H}_2\text{O})_6[\text{Zn}^{2+}\text{Fe}^{3+}(\text{TeO}_3)_3]_2 \cdot n\text{H}_2\text{O}$, $n \leq 3$: Trigonal symmetry enables a fully ordered host-guest structure

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The microporous crystal structure of zemannite was originally described in space group $P6_3/m$ (Matzat 1967; Mandarino et al. 1967; Miletich 1995), later revised to $P6_3$ (Cametti et al. 2017; Missen et al. 2019). Most recently the diffraction pattern of a single-crystal sample was re-investigated using a high-sensitivity Dectris Pilatus pixel detector (Effenberger et al. 2023). Unexpectedly, several uneven low-order $00l$ reflections showed unequivocally verifiable weak intensities clearly violating the 6_3 screw-axis reflection conditions. These observations promoted detailed X-ray crystallographic investigation to be resumed.

The crystal-structure type of zemannite is characterised by a honey-comb like $[\text{Zn}^{2+}\text{Fe}^{3+}(\text{TeO}_3)_3]^{1-}$ framework building channels along $[001]$. It consists of $M_2\text{O}_9$ dimers formed by two face-sharing MO_6 octahedra, $M = (\text{Zn}^{2+}, \text{Fe}^{3+})$ with $\text{Zn}^{2+}:\text{Fe}^{3+} \sim 1:1$. These dimers are linked by $(\text{Te}^{4+}\text{O}_3)^{2-}$ figures and form the channel walls. The channels are filled by the extra-framework constituents, i.e. $0.5 [\text{Mg}(\text{H}_2\text{O})_6]^{2+}$ cations per formula unit in addition to up to 1.5 interstitial H_2O molecules. So far, none of the space-group symmetries $P6_3/m$ or $P6_3$ was compatible with a fully ordered atomic arrangement. In space group $P6_3/m$ there is one $M = (\text{Zn}^{2+}\text{Fe}^{3+})$ position, thus an order of the M atoms is impossible. However, the ionic radii of the two M cations differ suggesting a tentative order and, furthermore, $\text{Fe}^{3+}_2\text{O}_9$ dimers besides $\text{Zn}^{2+}_2\text{O}_9$ dimers are not likely. Ordering of the extra-framework atoms is impossible within the given symmetry constraints for both space groups mentioned above. In the acentric space group the M position splits into two sites, $M1$ and $M2$; an order between Zn^{2+} and Fe^{3+} might be possible but could not be proofed so far (Cametti et al. 2017).

For this work X-ray diffraction data were collected at 298 ± 0.5 K, 200 ± 1 K, and 100 ± 3 K ($2\theta_{\text{max}} = 101.4^\circ$, $\text{MoK}\alpha$ radiation). Careful inspections of the entire images did not show any evidence for satellite reflections in the surrounding of the Bragg-peak positions. Furthermore, there is no hint neither for diffuse scattering nor for the appearance of superstructure reflections. Thus, an incommensurately modulated atomic arrangement or disorder phenomena in neighbouring channels are not likely.

A series of comparative refinement models were performed in the space groups $P6_3/m$ and its subgroups $P6_3$, $P\bar{6}$, and $P3$. Order of the Fe and Zn atoms in the framework is possible in all subgroups of $P6_3/m$. Due to mirror planes parallel to (0001) , space group $P\bar{6}$ allows Fe_2O_9 or Zn_2O_9 dimers, which contradicts the results of *ab initio* calculations (Cametti et al. 2017). A fully ordered atomic arrangement of the one-dimensional extra-framework atoms is possible in $P3$ only (Fig. 1). Refinements confirm the earlier postulated theoretical structure model with $[\text{Mg}(\text{H}_2\text{O})_6]^{2+}$ octahedra alternating with interstitial H_2O molecules along $[001]$ (Miletich, 1995). The interaction between these structural units as well as the bonding between the host and guest atoms is achieved solely by hydrogen bonds. The final refinements in space group $P3$ yield $R1 \sim 0.025$ for the entire data sets.

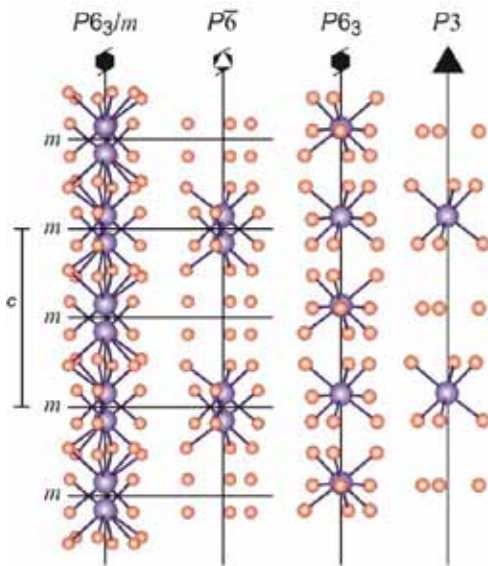


Figure 1. The extra-framework atoms and their distribution (full site multiplicity in the respective space group is shown). Mg and O atom position are shown as blue and red spheres, respectively. In $P3$ full order is achieved without the necessity of partial site occupations.

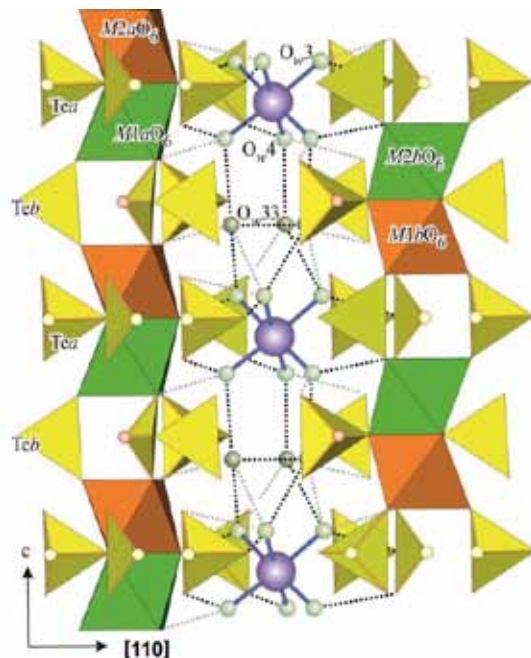


Figure 2. Detail of the atomic arrangement (space-group symmetry $P3$): the host structure consists of M_2O_9 dimers and TeO_3 groups. $M^{2+}O_6$ octahedra with $M = (Zn^{2+}, Fe^{3+})$ are shown in green and $M = (Fe^{3+}, Zn^{2+})$ in brown shades. – The channel is filled by $Mg^{[6]}$ atoms (blue) and H_2O molecules (O atoms in shades of green). Short and long O-H...O hydrogen bridges are indicated as dotted black and grey lines.

In accordance with the observed violation of the 6_3 screw axis, it is evident from crystal-structure refinements and crystal chemical considerations, that the atomic arrangement of zemannite is best described in space group $P3$. Zn^{2+} and Fe^{3+} ions are not fully ordered in the individual MO_6 octahedra but show a predominant occupation that explains the violation of the 6_3 screw axis. It is to be mentioned that neighbouring M_2O_9 dimers are differently orientated with Zn^{2+} respectively Fe^{3+} centred octahedra pointing upwards and downwards, respectively (Fig. 2). In contrast, symmetry $P6_3$ cause a parallel orientation of all dimers.

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Turning toolboxes into an ecosystem: How to make research software interoperable? Moderator

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I am an archaeologist and geochemist by training, currently working in the German National Research Infrastructure consortium for the Earth System Sciences (*NFDI4Earth*). The aim of the consortium is to provide a central access point for all resources related to research data management and data science in the Earth System Sciences. In addition, I am a core team member of *GlobalID*, the Global Lead Isotope Database. *GlobalID* aims to become an infrastructure for the publication, curation and access of lead isotope data in archaeology. Moreover, *GlobalID* further aims to bring the lead isotope community closer together, to create collaboration opportunities for researchers from less wealthy countries, and to provide training materials for the lead isotope method. In addition, I am author of the R package *ChronochRt*.

At the heart of all these endeavours lies my strong believe, that high-quality research can only be maintained in the future when its transparency is increased and hurdles (e.g. financial, infrastructural) are lowered. Besides making research data FAIR – findable, accessible, interoperable, reusable –, research software is a key component to turn this vision into reality. However, it won't be enough to have lots of tools at hand, as efficient and user friendly they may be. A crucial aspect is to design them, and the structure of the data processed by them, in a way that allows seamless passing of data between different software and, ideally, enable different software to directly communicate with each other. Consequently, not only the data but also the software must become interoperable.

Currently, there seems to be little coordination between the different groups working on research software in mineralogy, geochemistry, and neighbouring fields. However, aligning our efforts towards a common vision would be beneficial for all people involved in the development of such software and the community in general.

An extensible, open, and web-based research environment to understand geochemical data

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Introduction: The application of Data Science in Geochemistry and Cosmochemistry is becoming increasingly important and relevant to handle and work with the exponentially growing number of geo- and cosmochemical data over the last few decades. Exploring large databases provides the opportunity to research huge datasets to better understand the Earth's dynamics (Jiao et al. 2018). In the last 20-30 years, geochemical data and standards have been collected in databases such as GeoROC, EarthChem, MetBase, or AusGeochem.

The objective of this project is to create methods to work with databases such as, organising and cleaning of data, visualising data on different kinds of plots, statistical analyses of the geochemical data, detection and checking the influence of outliers, integrate these with existing tools such as pyrolite, IsoplotR, GeoPyTool and implement these tools in a modular, open, and web-based research environment. The overall goal is to combine geochemical data and software, which will enable new routes of research and possibly a new area of original scientific discoveries (Ma 2023).

Methods: The web application was developed using python and deployed through streamlit. The python source codes are publicly available on GitHub.

Results and Discussion: We developed a web page with which geochemical database data can be visualized on a map or various types of plots such as scatter plots (bivariate plots), category plots which show the normalised concentrations with respect to e.g., chondrite, or primitive mantle versus a list of user-defined elements and ternary plots. For this we used GEOROC data as an example. The entire database was initially organized by choosing a subset of required elements needed to complete the various web application components. The nan values were replaced by 0 and the columns with no information were dropped. Boxplots were used to identify the outliers. Those outliers, which might be a result of typing errors, were dropped.

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Rohstoffe für den Green Deal: woher nehmen?

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Die Europäische Union hat mit dem European Green Deal das ehrgeizigste Transformationsprogramm ihrer Geschichte initiiert. Die Reduktion der Treibhausgasemissionen sowie der Ausbau des Anteils erneuerbarer Energien werden gewaltige Mengen an mineralischen und metallischen Rohstoffen verbrauchen. Viele dieser Rohstoffe werden in der Union als kritisch klassifiziert und müssen daher zum überwiegenden Teil importiert werden. Hier ist vor allem die dominierende wertschöpfungsübergreifende Rolle Chinas in der Versorgung mit Rohstoffen und Zwischenprodukten zu nennen.

Trotz der Innovationen in Recyclingtechnologien und den Bemühungen zur Umsetzung einer Kreislaufwirtschaft werden primäre mineralische Rohstoffe weiterhin und sogar verstärkt genutzt werden müssen, um die Schlüsseltechnologien (Windkraft, Solarenergie, Batterien) und ihre Infrastruktur (Leitungen, Fundamente) zu versorgen. Es werden zusätzliche Mengen an strukturellen Materialien (Baurohstoffe, Stahl, Kupfer) und technologie-spezifischen Materialien benötigt. Letztere, beispielsweise Lithium, Kobalt, Seltene Erden, Indium und Germanium müssen derzeit zu nahezu 100% importiert werden.

Die Abhängigkeit der europäischen Industrie bezüglich der Rohstoffe für die Energiewende ist unumstritten und seit Jahren bekannt. Trotz intensiver Diskussion auf nationaler und europäischer Ebene hat sich die Situation für den Bergbau in Europa seit 30 Jahren nicht signifikant verbessert.

Der Vortrag wird besonders die Möglichkeiten der Versorgung mit mineralischen Rohstoffen aus europäischen Quellen beleuchten. Hier sind Potenziale für Lithium, Graphit, Seltene Erden und Kobalt, aber auch Baurohstoffe zu nennen. Die Eigenverantwortung der europäischen Länder impliziert, dass die Gewinnung zusätzlicher Rohstoffmengen genehmigt und geduldet werden muss, um größeren Schaden an Umwelt und Klima zu vermeiden. Erweiterungsverfahren oder Neuerschließungen sind jedoch mit erheblichen Problemen konfrontiert. Vielfältige konkurrierende Nutzungen müssen bedacht werden, und schließlich können Eingaben und Politik jedes Projekt kippen. Dies ist aus Sicht der Nachhaltigkeit der Versorgung mit den notwendigen Rohstoffen für die Energiewende nicht vereinbar. Somit ist der Ausbau der erneuerbaren Energien eine Herausforderung, die es an vielen Fronten zu meistern gilt.

Deformation and reaction of crustal rocks under high-pressure, high-temperature conditions

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In the plagioclase-rich lower continental crust, hydrous epidote-group minerals will, among other phases, replace plagioclase once minor amounts of fluids are available (Goldsmith 1981). It has previously been shown that reacting plagioclase aggregates are significantly weaker than their unreacted counterparts at otherwise identical conditions (Stünitz & Tullis 2001). Yet, it still remains unclear if the observed weakening is due to the nucleation and growth of inherently weaker product phase, e.g., epidote-group minerals, or due to inhibited grain growth in a polyphase aggregate as a result of Zener pinning. Our working hypothesis was the former: Epidote-group minerals are inherently weaker than plagioclase under the same experimental conditions. To test this hypothesis, we experimentally investigated the relative strength of pure epidote and pure plagioclase aggregates at a confining pressure of 1 GPa, two different temperatures (550 and 650 °C) and two different strain rates ($5 \cdot 10^{-5}$ and $5 \cdot 10^{-6}$ s⁻¹) using a Griggs apparatus. Furthermore, epidote-group minerals will be initially much smaller than plagioclase, they are replacing. Hence, we also investigated potential strength differences due to differences in grain size by deforming aggregates with a grain-size range of either ≈ 90 – 135 μm or < 25 μm . Under identical conditions, epidote aggregates are significantly stronger than their plagioclase counterparts even when partially reacted. Furthermore, we observe that reaction can induce a change in deformation behavior from distributed cracking to faulting in our epidote aggregates.

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