Did you know that the manufacturing of most metals is impossible without mineralogical analysis? Minerals are fundamental to our lives and have been mined for at least 40,000 years. When I collected my first mineral, it was the beauty of nature that fascinated me. Later as a student, I discovered the importance and value that applied mineralogy has for the manufacturing of most commodities that are needed in all parts of daily life.

Just recently while visiting Brazil, it became obvious how much mineralogy matters to create a sustainable future of the planet. I discussed with several mining companies how to implement mineral monitoring in up- and downstream mineral processing. Iron ore mines, for instance, must separate unwanted minerals to consistently produce high-quality ores. This process requires energy and creates tailings. Mineralogy matters to minimize both as much as possible. Another company had developed a procedure to manufacture cement from iron ore tailings, and a niobium–tantalum mine had started to extract lithium from material that was formerly deemed mine waste. A circular economy—from waste to new raw material—is already playing and will continue to play an important role for the extraction of metals from the Earth in a sustainable way.

Decades ago, mineralogical monitoring was considered a research technique owing to its complexity and long feedback times. Nowadays, technologies such as X-ray diffraction and hyperspectral imaging are suitable for industrial use. Robustness, measurement times of minutes or seconds, the possibility for automation, and, of course, digitalization allow direct implantation in mining operations and mineral processing. Not only fast and frequent mineralogical monitoring, but also geometallurgical modeling and prediction of the process parameters have become a “must” for mining operations. Key drivers are lower ore grades, geologically more complex orebodies, high metallurgical response variability, increased capital costs, and declining profit margins.

Geometallurgical and mineralogical knowledge is key to predict the risks associated with mineral processing and resource development, and to maximize the value of metal extraction. Modern geometallurgy seeks to integrate geoscientific disciplines with minerals and mining engineering because metallurgical performance is a function of mineralogy, grade, texture, and process conditions (e.g., Ehrig 2018). This next generation of information processing, with new analytical sensors and big data, enables the use of artificial intelligence and machine learning (ML) in the mining industry to further enhance performance and efficiency.

**Industry Examples**

Mineralogical monitoring is not completely new in the industry. For decades, it has been a standard method to control and steer, for example, cement production, aluminum smelting, or titanium mining and processing (Fig. 1). For the separation and extraction of titanium minerals, the importance of mineralogy is very clear as the two main minerals, rutile and anatase, have the same chemistry (TiO₂) but different crystallographic structures and properties during processing. Mineralogical knowledge is critical to ensure optimal conditions during separation and extraction.

Decreasing ore grades and increasing demand for copper have forced miners to look closer into copper ore mineralogy to master the transition toward green energy. Oxides require a different extraction method than sulphides, and even different copper sulphides, such as chalcopyrite or bornite, require different conditions during flotation (Fig. 2).

The steel industry, one of the largest producers of CO₂ emissions, has started the transition toward green steel manufacturing. This requires completely new technologies where hydrogen, instead of fossil energy, will be used. The mineralogy of raw materials and intermediate products is an important parameter that defines how efficient green steel making will happen using hydrogen in the future.

One of the most popular commodities these days is lithium. If mined from hard rock deposits, spodumene (LiAlSi₂O₆) is the mineral that must be separated and processed (Fig. 3). An important step to transform spodumene in lithium carbonate or lithium hydrate is calcination, which transforms α-spodumene into β-spodumene, which are phases of the same chemistry with different crystal structures. Mineralogical monitoring is mandatory for maximum lithium recovery during calcination and further downstream processing.

The list of examples where mineralogical monitoring plays a key role during mineral separation and metal extraction is long (e.g., Pöllmann and König 2022). Mineralogy is the link between ore formation and ore extraction. Smart mines of the future will use numerous sensors and the application of artificial intelligence, Internet of Things, and Big Data to digitally connect and optimize metal extraction and minimize the environmental footprint.

I am happy to see that mineralogy has turned from an academic science to an industrial tool over the past decade, bringing value to mining operations, and I am convinced that smart, efficient, and zero-waste mines will become reality in the upcoming decade.

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**Figure 1** Froth flotation to separate copper sulphides from gangue minerals. Zoomed view of two types of copper ores that require different processing. Sulphide ore (left) with chalcopyrite as main copper minerals for pyrometallurgical processing and oxidic ore (right) with atacamite as the copper mineral for hydrometallurgical processing (width of both images = 5 cm). Photos: Uwe König.

**Figure 2** World’s largest hard-rock lithium mine in Western Australia. Zoomed view of lithium ore with α-spodumene as main lithium minerals (width of image = 5 cm). Photos: Uwe König.

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If you’re active on LinkedIn, you might want to follow a geoscientist by the name of Uwe König. Uwe has a keen eye for interesting content, and regularly and eloquently posts on a wide range of topics, ranging from mineralogy to the environment and all the economics in between. The geoscience-focus of Uwe’s social media presence is an effective way to share knowledge and passion regarding our field with the broad network of students and professionals. Curiosity got to us and we tracked Uwe down to learn more about his background, current activities, and vision for the future. On the opposite page, Uwe shares his experience and insight into the future of the metals mining industry.

**Elements**: Hi Uwe! Tell us more about your involvement as a geologist on social media.

**Uwe König**: I was definitely a “late bloomer” for both private and business social media. It took me some time to figure out that social media is an ideal tool to connect with both my professional network and colleagues from different backgrounds.

What I like about social networks is that the information exchange happens in two directions: it is a good source to receive information from the community and on future trends; and at the same time, it provides the opportunity to share news about my experiences and activities and get feedback on them. As a geologist, I sometimes see nature with different eyes, and I love to share this viewpoint with my network. My LinkedIn posts under the title “Once a geologist” are quite popular and tend to remind many geologists of their own experiences.

Like with everything—the dosage is what makes the difference between usefulness and distraction. I try to limit my time on social media—especially while traveling, on weekends, and over holidays. Nothing is more precious than direct contact with friends and colleagues. By nature, human beings are, first and foremost, emotional creatures. Emotions are the drivers of our behavior and no social media—even that supported by artificial intelligence—can replace real live networking.

**Elements**: How did you come upon your career path?

**Uwe König**: I grew up in eastern Germany in the city of Halle (Saale), where I went to school and studied geology. My passion for Earth sciences started already by the age of 10. At that time, I never thought that it would be possible (after the fall of the Iron Curtain) to see all the “wonders of nature” that I knew only from my schoolbooks. By 12, I collected my first minerals in the Harz Mountains, and shortly thereafter knew that I wanted to be a geologist.

My geology studies started in 1994 at the Martin-Luther-University Halle-Wittenberg in Germany. The geological institute had just newly opened in 1992, hosting seven departments, which gave us the opportunity to build up detailed knowledge in all geoscience subjects, and also enabled a personal relation to the tutors. I tried to get a broad of knowledge base during the first years. The proximity to the Harz Mountains allowed me to dive deeper into the aspects of structural geology—guided by Prof. Dr. Max Schwab who taught and joined me during numerous field trips.

Applied mineralogy entered my focus during the second half of my study, thanks to my tutor and friend, Prof. Dr. Dr. Herbert Pöllmann. The direct influence on mineralogy on industrial processes was the driver for several research topics. My diploma dealt with the mineralogical quantification of iron ores, for which I spent several months at the Universidade Federal do Pará in Belém, Brazil. In 2006, I finalized my PhD thesis about manganous layered double hydroxides, phases that can also occur during the hydration of cement.

Since 2005, I have worked for Malvern Panalytical B.V. in the Netherlands, where I am now responsible for the development of new analytical solutions for the mining, minerals, and metals industry.

**Elements**: What are some of the best aspects of your job?

**Uwe König**: As scientist, it was always my wish to apply existing scientific knowledge to develop new practical applications. That’s exactly what I do in my current job: use new technologies that serve as a direct source for more efficient and sustainable exploration, extraction, and recycling of metals from ores. This is a little contribution to stop global climate change and enable a circular economy in the future.

Another one of my favorite aspects of my job is the contact, communication, and exchange of ideas with people working in different disciplines and environments from all parts of the world. Networking with opinion leaders and thinking out-of-the-box is the source of new ideas, solutions, and my motivation.

**Elements**: What do you think will be the biggest changes in the field in upcoming decades?

**Uwe König**: Besides global challenges, the mining industry will have to master geological and technological disruptions. High-grade ore deposits disappear and, accordingly, new deposits in remote locations move into the focus to satisfy the demand for green metals, enabling the energy transformation.

Mining operations will turn into smart mines driven by digital and automated solutions, and convert into zero-waste operations by avoiding and turning waste into new raw materials—step by step toward a circular economy. Such transitions can only happen if mining companies and mining equipment suppliers partner and develop new sustainable technologies together by thinking out-of-the-box.

**Elements**: Tell us about some things you’ve learned in your job?

**Uwe König**: One of the things I learned quickly in the industry is that there is only limited time to investigate a problem and find a solution. But, with this, I also learned that, sometimes, the key is not the latest technology, highest accuracy, or lowest detection limit, but rather a “good-is-good-enough” solution that solves a problem. My advice for young researchers is to get a broad knowledge base, gain experience, and to try out every subject before specializing. If you do something with passion, you will be good at it, be satisfied, and achieve great things.

**Elements**: What will you be doing in the future?

**Uwe König**: My goal is to bring in new ideas, technologies, and solutions in the fields of exploration, extraction, and recycling of metals from ores. I have the opportunity to share news about my experiences and activities and exchange of ideas with people working in different disciplines and environments from all parts of the world. Networking with opinion leaders and thinking out-of-the-box is the source of new ideas, solutions, and my motivation.