Precious and critical metal potential of historic Cu-Au-As mine waste in the Eastern Alps

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Introduction

For the world to transition from fossil fuels to renewable energies, we need both an amount and a diversity of raw materials the likes the world has never seen.
For example, to build the required power grid to move to 'green' electricity we need to mine the same amount of copper in the next 30-40 years as we have in all of human history combined (Cathles and Simon, 2024). The impossibility of finding such a large amount of copper, and other critical metals, in such a short time requires us to identify alternative sources of these critical and strategic metals.

While we will likely not find such large quantities of these metals in new deposits, however during much of human history the extraction rates for many metals were less than 50%. This means that in the mine waste of historic districts we might have as much metal in the mine waste as was originally produced.
This is particularly true of the historic Cu-Au-As mining districts of the Eastern Alps. Recovery rates for the produced metals such as copper and gold were between 50-66%, and with the rest, largely in the form of sulfide minerals, ending up as mine waste (Paar et al., 2006). This sulfide rich mine waste is both a source of groundwater contamination as well as a source of critical metals that tend to associate with Au and Cu (i.e. As, W, Bi, In, Te; (Gopon et al., 2019).

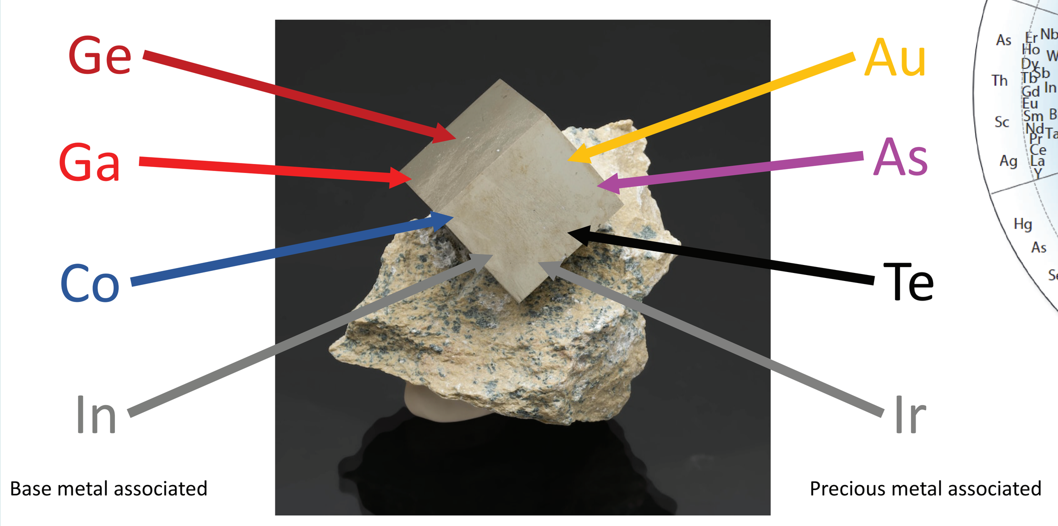


Figure 1: Critical metal containing sulfide minerals can be generally subvidivded into two main types: 1) those associated with base metal deposits and their associated minerals, (ex. Galena, spahlerite) and 2) those associated with precious metal deposits and the assocaited minerals (ex. pyrite, arsenopyrite).

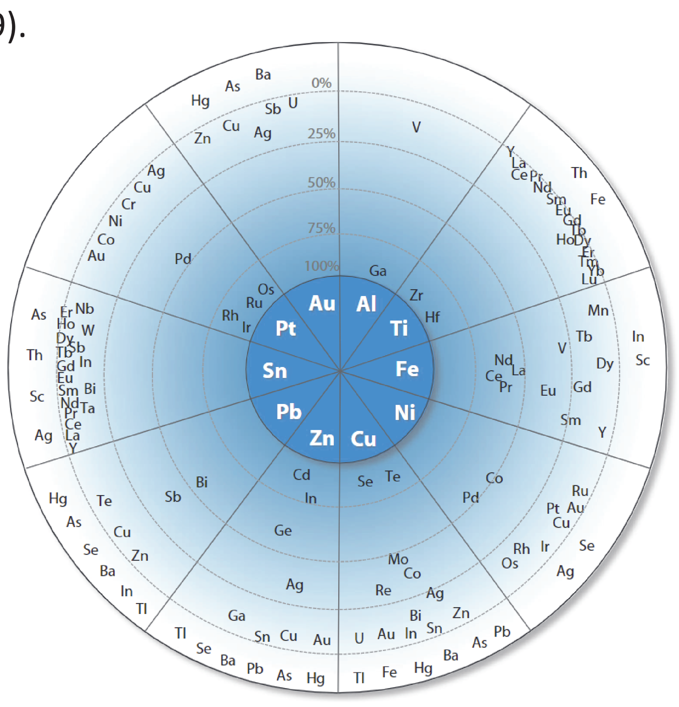
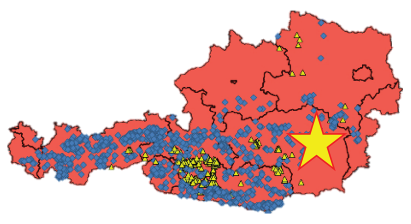


Figure 2: All metal deposits are polymetallic. The wheel of associated (Nassar et al. 2015) shows the full range of metals associated with various metal deposit types. Particularly relevant to us is the link between Cu and Au deposits, and the critical metals that can be found therein.

Environmental Impact

Historic mining activity has long term environmental impacts. Much of this environmental damage stems form the sulfide minerals that were dumped on waste piles, and contaminate the environment in the form of acid mine runoff.
To take the example of the Strassegg historic As-Au mining district (Strassegg, Styria), which was mined from the 14th to the 16th century, the soil still contains ~800 µg/g As and the rivers up to 370 ng/g As. This contamination is concentrated near historic waste and ore processing piles.



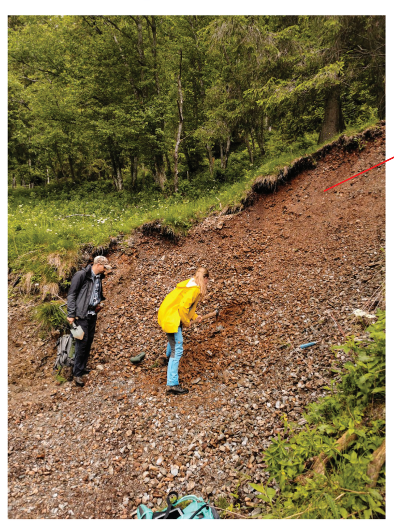


Figure 3: Waste pile associated with the As roasting pit in Strassegg. Arsenic concentrations therein are above our analytical detection limits (10,000 µg/g). A stream near this site has been measured as containing 370 ng/g As.

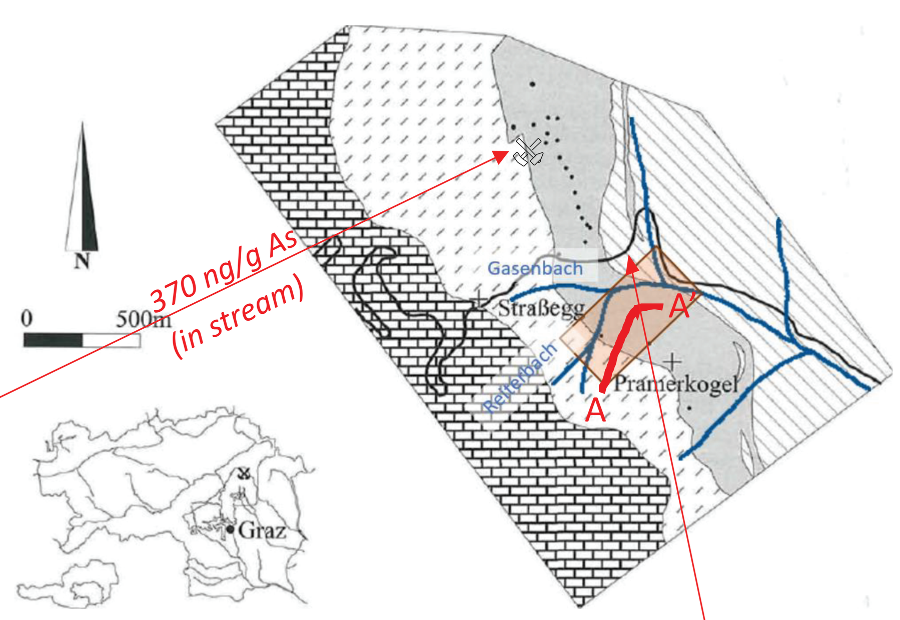


Figure 4: Geologic map of the Strassegg district with the As roasting pit and a geochem sampling profile noted.

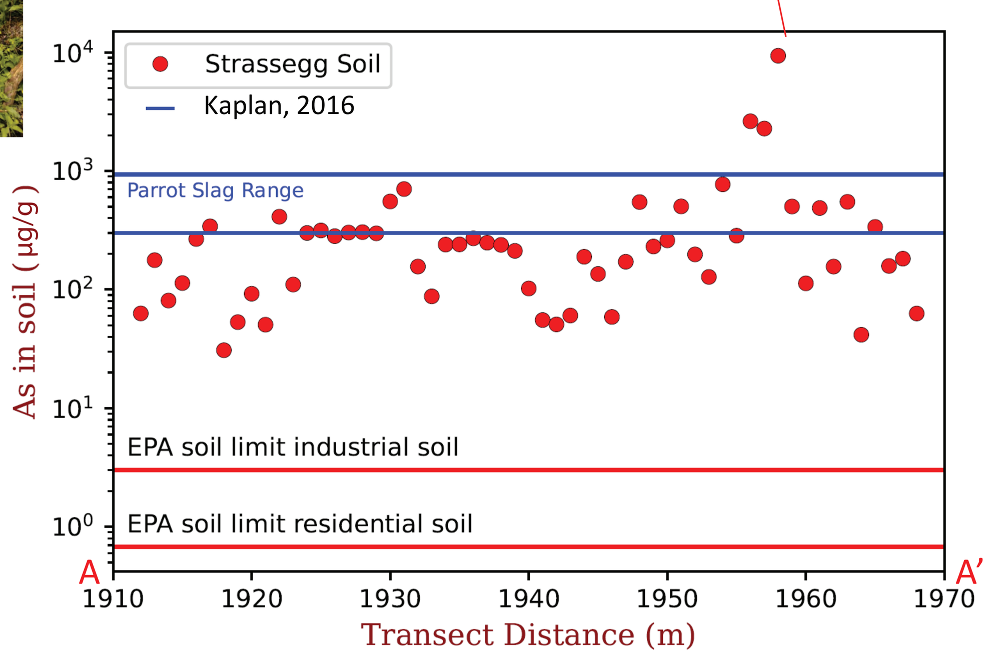


Figure 5: Results of a soil sampling profile across the mineralization. EPA limits for soils, as well as the As concentration of one of the worst contaminated slag piles in the United States (Parrot Slag Pile, Butte Mining District, Montana; Kaplan, 2016) are given as a reference lines.

Even 300 years after the cessation of mining the Strassegg region is still heavily impacted by this legacy. If the mine waste can be removed, it would go a long way to remediating this harshly contaminated landscape.
While Strassegg is a particularly stark example, we have measured high levels of arsenic in the streams in/around multiple mining districts.

Economic Potential

By combining whole rock geochemistry, geophysics, and advanced micro- to atomic-scale characterization techniques we have produced estimates of the raw material potential of the select Cu-Au-As mine waste sites in the Eastern Alps; inlcuding Strassegg, Gastein-Rauris, Pusterwald, Kothgraben, and Flatschach. What is clear from this data is that there remains much Cu, Au, As, and associated critical metals, generally in the form of trace metals in sulfide minerals.

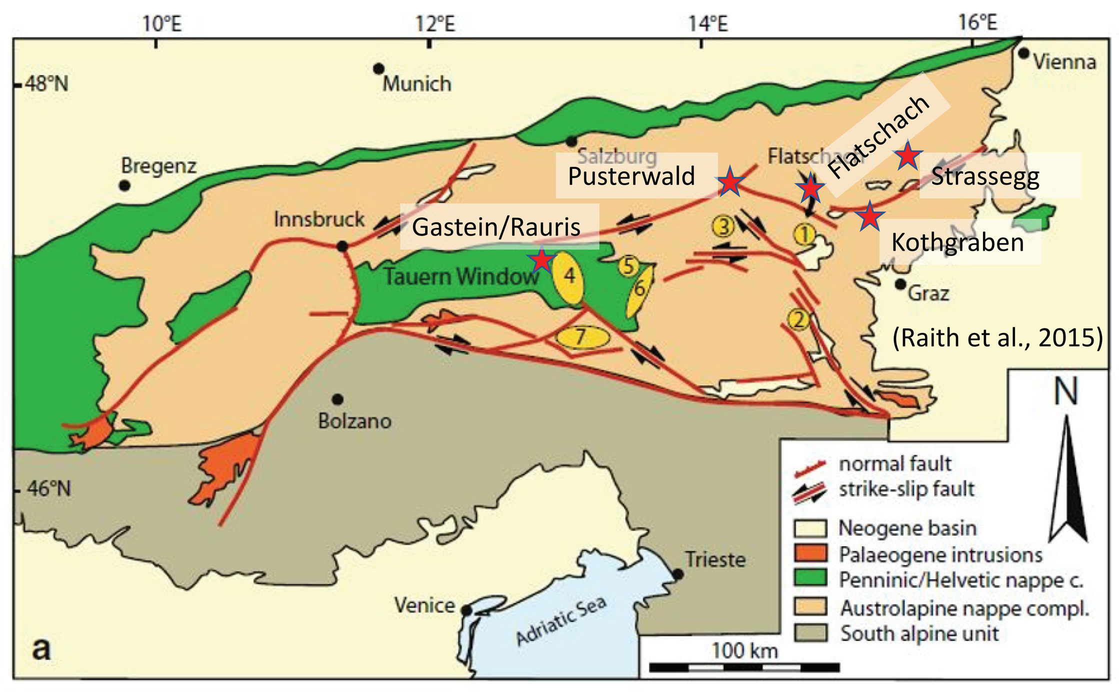


Figure 6:Simplified Geologic map of the Eastern Alps (from Raith et al. 2015), overlain with sites were sampling and resource estimates have been conducted.

Based on extensive sampling of waste rock piles, fieldwork, and waste rock pile volumes from the *Geosphere Austria*, we are able to estimate resource potentials in each district.
Below is an example from the **Flatschach Cu-Au district, Spielberg, AT.**

34 Mine waste sites w/ >300,000 tons

	average grade (µg/g)	estimated metals
Au:	0.12	43 kg
As:	1,016	330,000 kg
W:	4	1,300 kg
Cu:	2,812	1,000,000 kg
(avg. Cu grade during mining was 5,000)		
Co	56	20,000 kg
Ni:	55	19,000 kg
Cr:	50	17,000 kg
Te	0.5	170 kg
In	1.2	416 kg
Ga	13	152 kg
Calculated total worth	=	**€15-20 million**
Calculated total profit	=	**€1-6 million**

Table 1: Average composition of a representaitive mine waste pile in Flatschach (Revier Brunngraben), and estimated metal amounts in the mine waste. Estimated worth calculated from the avg. comp and the surface area of the waste piles (Geosphere Austria Haldenkataster), calculated profit based off quotes for necessary equiptments and average mining costs / tonne.

Figure 7: Historic map of the Flatschach District, overlain with the surface exposure of mine waste piles in blue. (Data source: GeosphereAustria Haldenkataster)

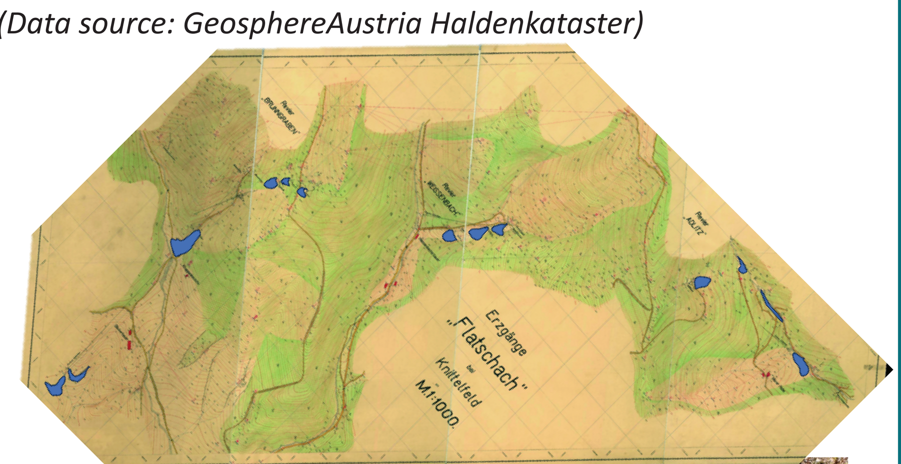


Figure 8: Field photographs of 2 cross sections through the top ~2m of a mine waste pile in Flatschach (Revier Brunngraben). Bergeisen for scale is 95cm.

European Resource Potential
Example Austria

While the Eastern Alps are rich in ore deposits, they are by no means alone in Europe as potential sources of critical metals.
Similar deposits to those we have investigated occur in Slovenia, France, Germany, Spain, Italy, and Switzerland, and will have similar Cu, Au, and critical metal concentrations.

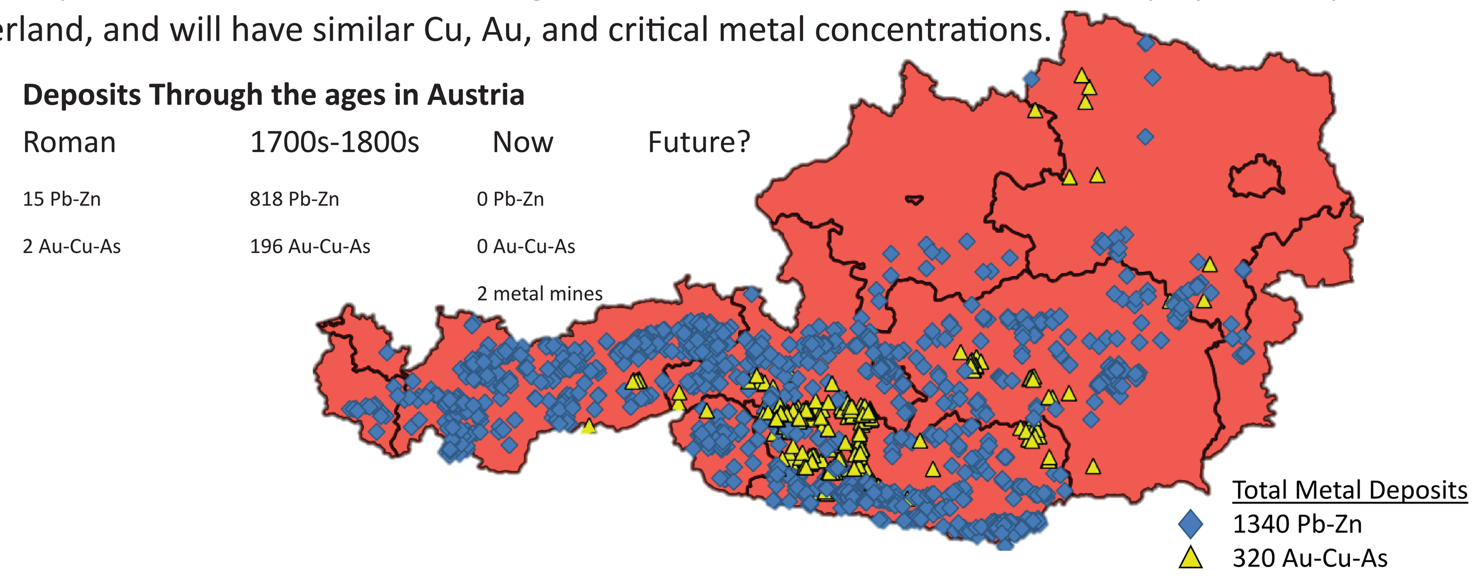


Figure 8: Map of Austria showing localities of Pb-Zn and Au-Cu-As deposits. (Datasource: IRIS database, Geosphere Austria)

In total Austria contains ~4,000 mine waste sites with a total esimated 50 million tones of Cu,Au, As mine waste. The largest 70 of these contain an estimated:
150 million kg Cu; 6,500 kg Au; >>60 million kg As; 7 million kg W, 90 million kg Co, 40 million kg Ni, 20 million kg Cr, 2 million kg Te, 150 million kg In, and 150 million kg Ga

However: Estimating resource potential is far removed from being able to actually re-mine these waste piles. We are therefore starting an pilot project in **Flatschach** (funded by *Horizon Europe*, in collaboration with Mining Engineers, Env. Chemists, and Metallalurgists) to develop new mining, ore processing, and metallurgical techinques to be able to process this low-grade (high As) ore.

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