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Release of Uranium from a Former Iron Mine, 30 Years after Flooding

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Abstract

The Stripa mine, located in Bergslagen, Sweden operated from the Middle Ages until 1977 and later served as a research facility for SKB until 1991, after which it was flooded. Recent studies show a notable increase in uranium concentrations in the mine water, reaching nearly 1 mg/L at 200 m depth, compared to historical levels of 10 µg/L. This increase is linked to uranium(IV) oxidation by elevated dissolved oxygen. Further research should investigate key biogeochemical processes controlling uranium transport and long-term environmental persistence. The findings highlight regional environmental risks, including potential contamination of wells, emphasizing the mine's long-term environmental impact.

Keywords: Uranium, mine water, environmental impact, biogeochemical processes, environmental risks

Introduction

The Stripa mine, situated in Bergslagen in the Guldsmedshyttan region, Sweden (59.70617, 15.09578) has a long history of iron ore extraction dating back to the 1400s (Willim 2008). Mining operations ceased in 1977, leaving behind a 490-meter-deep mine. The mine was subsequently repurposed by the Swedish Nuclear Fuel and Waste Management Company (SKB) as a research facility until 1991. During this period, extensive hydrogeological studies were conducted with a focus on groundwater flow, radionuclide transport, and engineered barriers for nuclear waste isolation in granitic rock (Nordstrom *et al.* 1989, Waber & Nordstrom 1992). This has provided some fundamental knowledge on solute transport in fractured crystalline rock, highly relevant to the present study. After the research concluded, the mine was flooded, leading to clear hydrogeochemical changes, and the surface facilities were used for industrial purposes (Eriksson & Larsson 2007). In 2006, the remaining structures were declared buildings of historical value, preserving their industrial heritage (Willim 2008).

The mine's geological setting features uranium-rich granitic bedrock, interspersed with hematite, magnetite, and quartz. Historical investigations in the 1950s identified uranium mineralization, particularly pitchblende at the 350-meter level. Compared to other regional rock is the content of uranium in the Stripa mine clearly elevated (Tab. 1) (as cited in: Allard, Sjöberg, Karlsson 2017). Recent water quality assessments and geochemical modeling have indicated changes in uranium concentrations and speciation, warranting further evaluation of the mine's environmental impact.

Table 1 *Abundance of uranium in regional bedrock and in the Stripa mine.*

Bedrock	Regional, granite	Regional, metamorphic	Stripa, shallow	Stripa, deep	Stripa, 107 m	Stripa, 408-456 m	Stripa, 760 m
Uranium (g/ton)	18+15	6+1	27+6	37+6	32	31	35

The key objective of this study is to synthesize historical data and data from recent sampling in an attempt to further characterize the mine-water and understand its potential environmental impact on the surroundings upon release from the mine.

Methods

Sampling and Analysis

Water samples were collected during multiple campaigns, including those conducted in 2017 and earlier SKB-led studies from 1979 to 1986. Samples were obtained from streams near the site, the mine shaft overflow, and within the mine shaft itself down to a depth of 200 meters (Fig. 1). Analyses included measurements of pH, dissolved oxygen, metal concentrations, and anions. Advanced methods, such as inductively coupled plasma mass spectrometry (ICP-MS), were used for uranium quantification.

Geochemical Modeling

Geochemical modeling using Visual Minteq was conducted to determine uranium speciation in the mine water. The model incorporated measured concentrations of dissolved oxygen, carbonate, and other geochemical parameters. It predicted the dominant uranium species in both the shaft water and discharge water, providing insights into uranium mobility under current conditions.

Results and Discussion

Hydrogeological Characteristics

The mine's groundwater can be categorized into three distinct types based on historical data (1979–1986) (cf. Fritz, Barker & Gale 1979, Nordström 1983, Gale *et al*. 1987):

1. Shallow Oxic Water: Shows influence from surface water, with low salinity and pH 5–7.

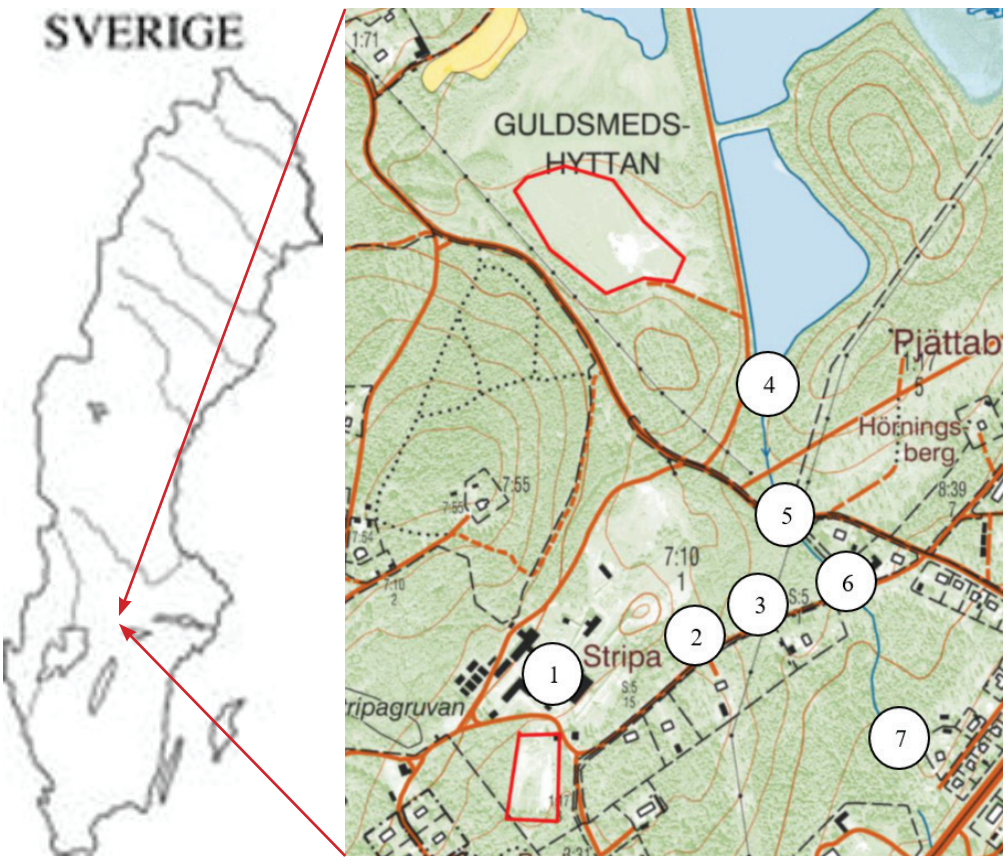

Figure 1 *Map over sampling locations. The old mine site is located in mid/southern Sweden, some 170 km west of Stockholm.*

Table 2 Groundwater composition, historical (pre-1991) and recent (2017) data.

	Year	pH (range)	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	SiO_2
Shallow	Pre-1991	5.2-8.1	5.7	1.7	3.8	16.3	4.6	10.9	68.1	10.9
Intermediate	Pre-1991	8.6-9.2	46.2	0.2	0.2	19.1	56.3	2.7	72.7	11.2
Deep	Pre-1991	9.3-10.1	224	0.7	0.1	125	513	71.5	12.2	13.7
0–200m	2017	7.4-7.5	18.2	2.2	9.2	55.2	24.7	27.3	189	4.4

2. Intermediate Anoxic Water: Exhibits Ca-HCO3 composition, low salinity, and pH 7–8.
3. Deep Anoxic Water: Characterized by Na-Ca-Cl composition, high salinity, and pH >9. The water is 8,000–30,000 years old and unaffected by modern surface water infiltration.

In 2017, shifts were observed in groundwater composition (mg/L, Tab. 2). Elevated concentrations of K, Mg, Ca, HCO_3, Cl, and SO_4 were detected, with a reduction in depth-dependent gradients. This suggests mixing of shallow and deeper waters in the mine shaft.

Uranium Dynamics

Recent measurements reveal a dramatic increase in uranium concentrations, reaching nearly 1 mg/L at 200 m depth. This marks a tenfold increase from historical averages. Dissolved oxygen levels were measured at 37.2% saturation at 15 m depth, 23.1% at 200 m, and 87.7% in the discharge water, indicating mixing with surface water. The oxidation of uranium(IV) to uranium(VI) appears to be the primary driver of elevated uranium levels. This process is facilitated by the mine's transition from anoxic to oxic conditions. Geochemical modeling confirms that uranium exists predominantly as carbonate complexes in the mine water, with carbonate complexes being the dominant species (Tab. 3).

The dominance of carbonate complexes highlights the role of elevated carbonate levels in enhancing uranium mobility and solubility. Historical uranium concentrations ranged from 1 to 10 µg/L, peaking at 90 µg/L in oxic waters collected in drillholes in the mine as well as private wells (PW1–5) within 2 km radii from the mine shaft. , while current concentrations exceed 900 µg/L due to these geochemical shifts (Tab. 4).

Environmental Risks

Elevated uranium concentrations pose potential risks to the surrounding environment. While uranium levels in streams and surface waters remain within acceptable limits (Tab. 5), the potential contamination of private wells in the vicinity is concerning. With the estimated flow out of the mine the input of uranium to the downstream recipient is in the range of 10 to 100 kg of uranium annually. Further studies are required to evaluate the extent of uranium mobility and its environmental impact on regional water quality.

Table 3 Uranium speciation in shaft and discharge water.

Species	% in shaft surface water	% in discharge water
$Ca_2UO_2(CO_3)_3$ (aq)	68.0	60.4
$CaUO_2(CO_3)_3^{-2}$	28.7	28.7
$UO_2(CO3)_2$-2	1.59	4.16
$(UO_2)_2CO_3(OH)_3^-$	0.85	3.03
UO_2CO_3 (aq)	0.50	3.06
$UO_2(CO_3)_3^{-4}$	0.33	0.34
$UO_2(OH)_2$ (aq)	0.04	0.18
UO_2OH^+	0.02	0.12
$UO_2(OH)_3^-$	0	0.02

Table 4 *Historical (pre-1991) (as compiled in Allard, Sjöberg, Karlsson 2017) and recent (2017) concentrations of uranium in groundwater, in and around the mine according to depth.*

			Uranium (µg/L)	
	Year	Depth (m)	Average range	Maximum
PW1–5	pre-1986	40–60	0.8–8	90
Mine	1986–91	0–80	n.d.	90
Mine	1986–91	89–104	0.8–11	n.d.
Mine shaft	2017	0–200	929–987	n.d.
M3	pre-1986	336–350	8–11	12
E1	pre-1986	357–385	2–10	13
N1	pre-1986	357–401	1–2	9
V1	pre-1986	449–863	0.1–2	35
mine	1986–91	765–861	0.1–2	n.d.
mine	1986–91	908–969	0.1–0.8	n.d.
V2	pre-1986	792–1232	<0.1–0.8	8

Recommendations

To address the environmental risks associated with the Stripa mine, several immediate actions and future research initiatives are recommended. First, it is essential to establish a long-term groundwater monitoring program that focuses on tracking uranium concentrations, dissolved oxygen levels, and other key parameters. This will provide critical data to assess ongoing changes in water quality and potential contamination risks. Additionally, raising public awareness is crucial; local communities should be informed about the potential risks associated with using private wells near the mine site to ensure they can take necessary precautions.

Looking ahead, further research is needed to better understand and mitigate the environmental impact of uranium contamination. One key area of study is the biogeochemical processes driving uranium mobility in the mine's groundwater, which will help clarify the mechanisms controlling its transport and persistence. Moreover, it is important to assess the feasibility of in situ remediation techniques, such as reactive barriers, to limit uranium release and prevent further environmental impact. Lastly, comprehensive sediment and biota studies should be conducted to evaluate the ecological consequences of uranium contamination in downstream environments, ensuring that the long-term effects on aquatic ecosystems are well understood and properly managed.

Conclusion

The Stripa mine presents a unique case study in the long-term environmental impacts of flooded mines in granitic rock. While historical operations and recent research activities have provided valuable insights, the recent rise in uranium concentrations underscores the need for ongoing monitoring and targeted remediation. Geochemical modeling indicates that carbonate complexes dominate uranium speciation, contributing

Table 5 *Average concentration of uranium, pH and electrical conductivity (EC) in sampling points, in (1) and around the mine (2–7) according to Fig. 1.*

	1	2	3	4	5	6	7
	mine		downstream	creek			
	shaft	discharge	discharge	upstream		mixing point	downstream
Uranium (µg/L)	966	227	266	5.7	4.9	9.4	6
pH	7.44	7.15	7.39	6.48	6.91	6.92	7.24
EC (µS/cm)	370	235	253	88.2	88.2	88.8	94.2

to its mobility. Collaborative efforts between researchers, local authorities, and the community will be essential in ensuring the site's safe integration into the surrounding region while preserving its historical and industrial significance.

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References

Nordstrom DK, Ball JW, Donahoe RJ, Whittemore D (1989) Groundwater chemistry and water-rock interactions at Stripa. Geochim Cosmochim Acta 53:1727–1740

Allard B, Sjöberg V, Karlsson S (2017) Groundwater and surface water from Stripa. Water quality in the mine and outflow of metals from the premises. RBS 17-06 R, Remedy by Sweden AB

Eriksson I & Larsson P (2007) Stripa gruva, Översiktlig miljöteknisk markundersökning, 29pp, Internal Report 6242-001, Structor Miljöteknik AB

Willim A (2008). Stripa – från järnmalmsgruva till industriminne. Geoarchaeological Research Report. UV Uppsala rapport 2008:12

Fritz P, Barker JF, Gale JE (1979) Geochemistry and isotope hydrology of groundwaters in the Stripa granite. Results and preliminary interpretations. Swedish-American Coopertive Program on Radioactive Waste Storage in Mined Caverns in Crystalline Rock. Earth & Environmental Sci. Stripa Reports 1977–86, KBS/LBL

Gale J, MacLeod R, Welhan J, Cole C, Vail L (1987) Hydrogeological characterization of the Stripa site. Stripa Project TR 87-15, SKB, Stockholm

Nordström DK (1983) Geochemical characteristics of groundwater at Stripa. Proc. Symp. Geological Disposal of Radioactive Waste. In Situ Experiments in Granite. OECD/NEA, Paris, p 143–153

Waber N, Nordstrom DK, 1992. Geochemical modeling of granitic ground waters at the Stripa site (Sweden) using mass balance approach. In Kharaka YK, Maest AS (Eds). Proc. 7th Internat. Symp. on Water-Rock Interactions (WRI-7), Internat. Assoc. Geochem. Cosmochem. p 243–246