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FORECASTING AND ASSESSING EUROPE'S
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WP7 Historic Mine Sites revisited

Case Study

The Riddarhyttan mining field, Bergslagen, Sweden

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(Photo: Helge Reginiussen, SGU)



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1 Introduction

1.1 The Bergslagen ore district

The Bergslagen ore district is a mineralized, arc-shaped area in central Sweden that has been a metal producer for more than 1 000 years. With more than 10 000 known mineral occurrences and deposits it is one of Sweden's most important mining districts (Fig. 1).

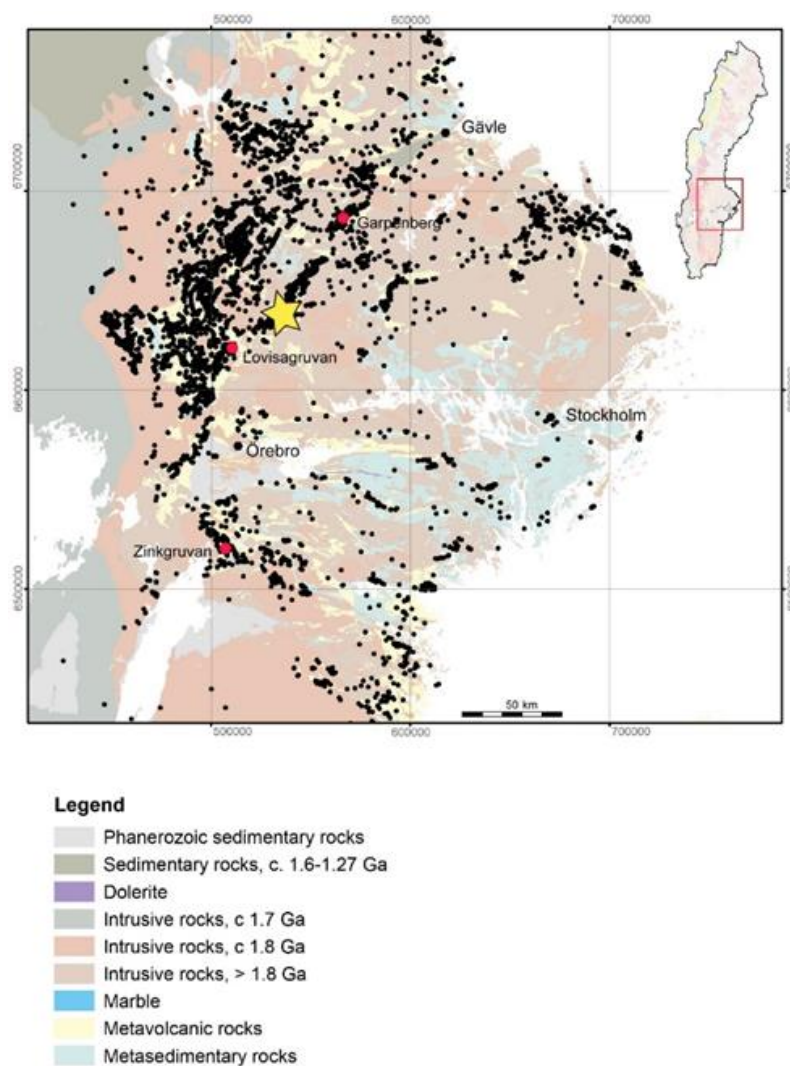


Figure 1: Metallic occurrences and deposits (black dots) in Bergslagen (data from SGU Mineral resources database). Active mines are named and marked with red dots. Yellow star shows the location of Riddarhyttan.



Bergslagen hosts a diverse range of ore deposit-types including banded iron formations, skarn- and carbonate-hosted iron ore, Mn-skarn- and carbonate-hosted iron ore, apatite-bearing iron ore, stratiform and stratabound polymetallic base metal sulphide ores, W-skarn and REE deposits (Stephens et al. 2009, Eilu 2012).

The major part of Bergslagen is dominated by Palaeoproterozoic predominantly felsic magmatic rocks and forms part of the 2.0–1.8 Ga Svecokarelian orogen inferred to have formed along an active continental margin in convergent plate boundary setting.

Archaeological evidence shows that hard-rock iron ore mining in Bergslagen began during the Roman Iron age (0-400AD). Bloomery furnaces, dated to around 100 AD, with fragments of magnetite ore have been excavated north of Uppsala. Archaeological excavations and 14C dating of the Lapphyttan blast furnace in the Norberg area indicates that iron was produced with more modern techniques during the 12th century (Almevik et al. 1992).

More than 575 million tonnes of ore has been mined in Bergslagen since the mid-19th century (SGU Mining production database). However, the actual figure is higher because several thousand small mines were mined and abandoned before reliable nationwide statistics were maintained. Three base-metal mines are currently active in Bergslagen.

2 Mining history of Riddarhyttan

Mining at Riddarhyttan is documented from the late 14th century (Carlborg, 1923). Due to its unusually rich mineral diversity, the Riddarhyttan area has been an important location in terms of scientific discoveries. The chemical elements cobalt, cerium, lanthanum and the minerals cerite and bastnäsite were first discovered in samples from Riddarhyttan. In 1735 it was shown by G. Brandt that the presumed arsenopyrite that posed major problems in the mine was cobaltite and small amounts of cobalt have been produced over the years. In 1751 Cronstedt (the scientist who discovered nickel) described an unknown reddish substance called “Bastnäs Tungsten” in the St. Görans copper mine in the Nya Bastnäs field in Riddarhyttan. The mineral he discovered is presently known as cerite-(Ce). The mineral was further investigated in the early 19th century by Hisinger & Berzelius (1804) who in concluded that it consisted of a new element which they named cerium after the asteroid Ceres observed shortly before. During the second half of the 19th century about 200 tons of “cerite” ore was produced from Ceritgruvan (and other mines) in the Bastnäs field (Carlborg 1923). These mines are type locality for the mineral bastnäsite (see Andersson 2004 and references therein).



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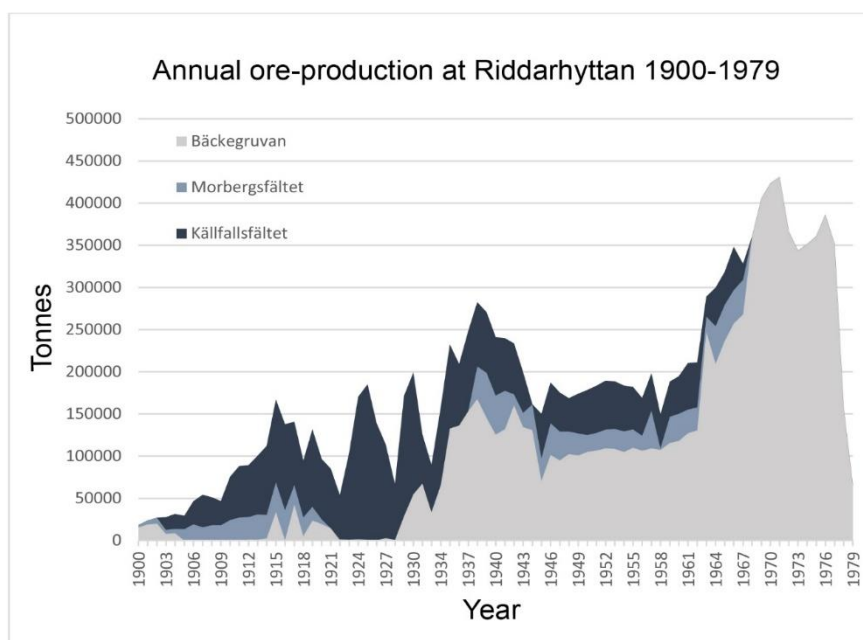


Figure 2: Annual iron-ore production (lump-ore and ore for concentration) at the three largest mines in Riddarhyttan. Additional production has occurred from small mines in the northern part of the Riddarhyttan area.

Table 1: Mining and processing at Riddarhyttan. (Mt=Million tonnes)

Ore production and processing 1900–1979		Tonnage (Mt)	Fe %	S %	Cu %	Mo %
Mined	Källfallsfältet	4.11	45.3	0.12	-	-
	Persgruvan (Morbergsfältet)	1.31	43.9	0.29	-	-
Processed at concentrator	Riddarhytte odalutmål	9.34	35.0	1.01	-	-
	Källfallet	3.57	36.9	0.19	≈0.02	≈0.05
	Bäckegruvan	9.27	34.0	1.35	≈0.1	-
Tailings	Källfallet	2.01	8.68	0.16	-	-
	Bäckegruvan t.o.m 1963	2.22	9.73	2.60	-	-
	Bäckegruvan 1964-1979	3.22	11.2	0.40	-	-



Geijer (1923) defined the Riddarhyttan field as the mines and mining areas that fit within an approximately 2-kilometre-wide and 6-kilometre-long zone that extends north-east from Lake Lien in the southwest to the Älgtorps field in the northeast (figure 3). The host rocks to the numerous iron and base-metal massive sulphide deposits in the Riddarhyttan field are altered Palaeoproterozoic supracrustals dominated by felsic metavolcanics and metasedimentary units (Ambros 1983).

Iron ore has been the most important product at Riddarhyttan during all years, but periodically copper, cobalt, REE and molybdenum have been extracted, either as a by-product of iron ore extraction or as the main product at some of the mines.

Exploration for copper in the area was initiated by King Gustav Vasa in the mid-16th century, which resulted in some minor discoveries and test mining, but copper mining ceased during the last decades of the 16th century. Renewed activity commenced in the 1620-ies, but the copper mining struggled until the rich copper deposits in Myrbacksfältet was discovered at the end of that century (Tegengren 1924). The last year for copper ore production from the Riddarhyttan field was 1873, but copper concentrate from iron ore processing in the concentrator at Bäckgruvan continued until the closure of all mining activity in the Riddarhyttan mining field in 1979.

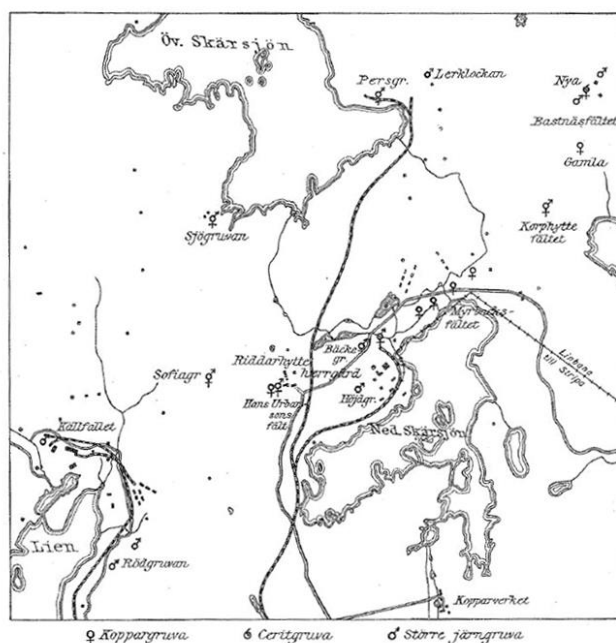


Figure 3: Map from Geijer (1923) showing an overview of mines in the Riddarhytte field.



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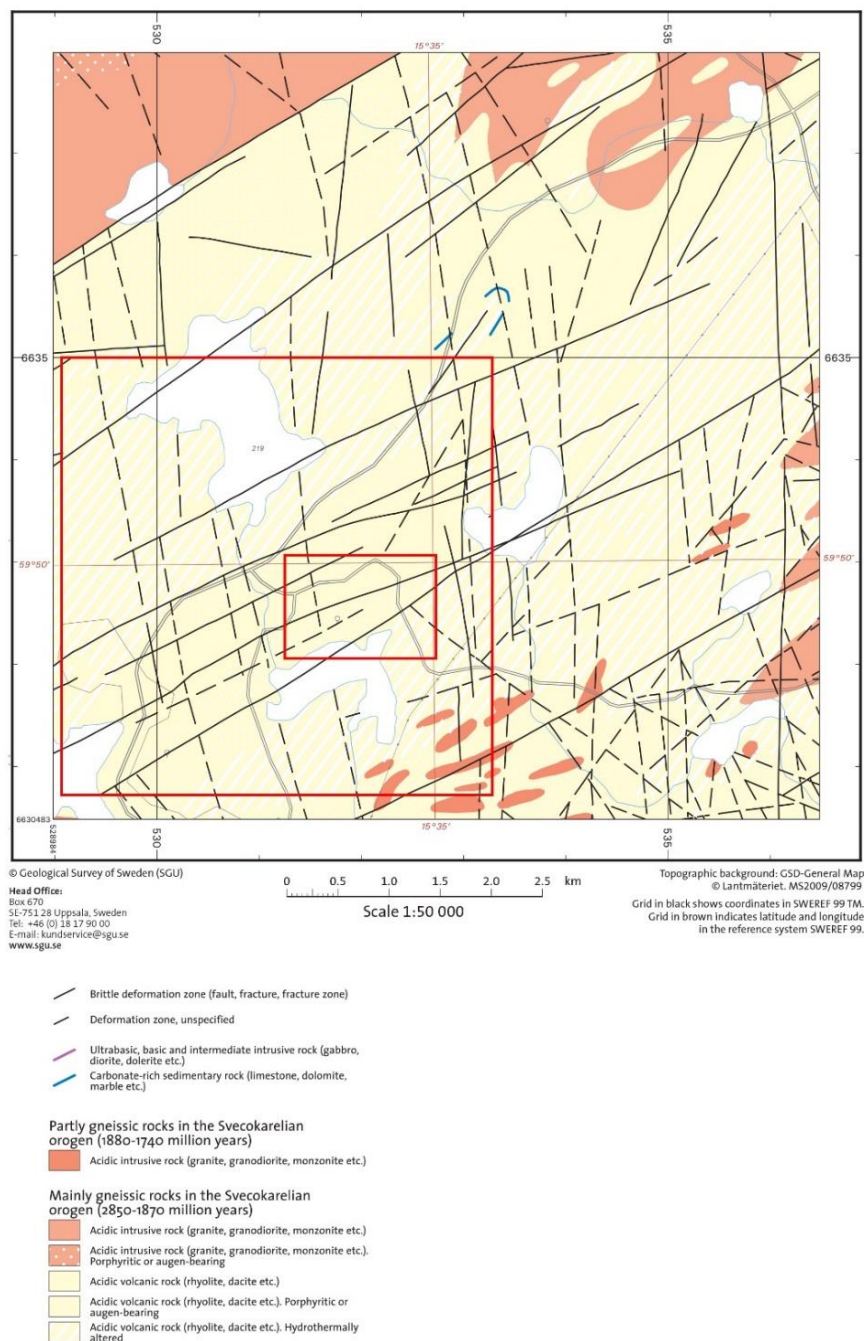


Figure 4: Simplified geological map of the Riddarhyttan area. Large red square shows outline of Fig. 2. Small red rectangle shows outline of Fig. 6.



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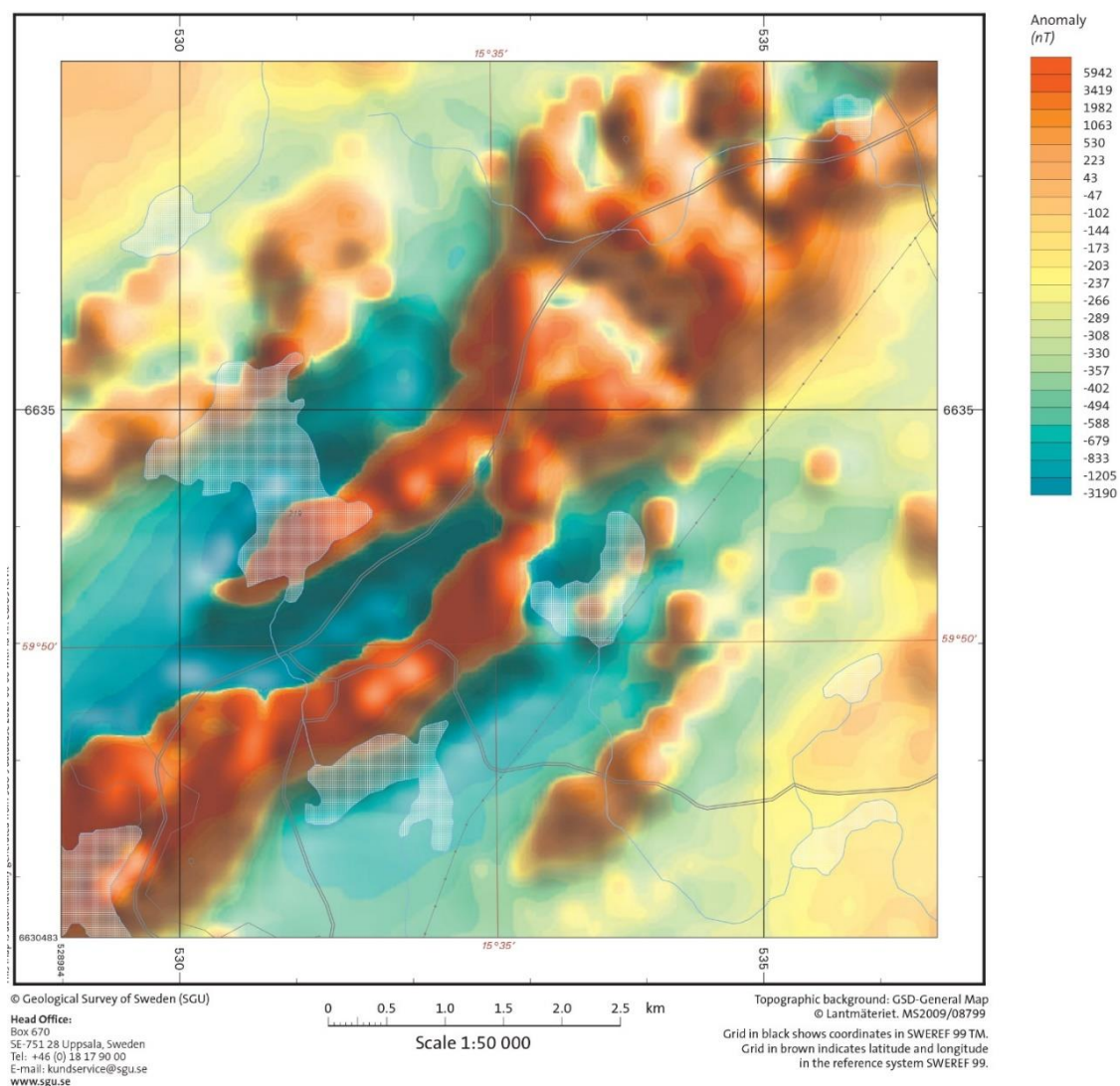


Figure 5: Magnetic anomaly map of the same area as Fig. 4. The map shows measured variations in the magnetic total field after subtraction of the geomagnetic reference field (DGRF 1965.0) and is based on airborne measurements performed at an altitude of 30 to 60 meters.



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2.1 Bäckegruvan and Källfallet

On closure of Bäckegruvan in 1979, mining had reached the 360-metre level, a modest depth by today's standards. A resource estimate for the Bäckegruvan and Persgruvan mines which was updated one year before operations stopped show a remaining tonnage of 10 million tonnes at 34.4% Fe and an additional 0.67 million tonnes of low-grade iron-ore with 0.37% Cu (Fagersta Bruk 1978). In addition, it was estimated that the remaining ore in other parts of the Riddarhytte field was 14.5 million tonnes (see Table 2). Based on information from drilling, geophysics and geological investigations it can be assumed that the orebody continues below the current mined level and to the north (Fagersta Bruk 1978). Tonnage and grade information about REE and cobalt and copper were not included in the historic ore estimate.



Figure 6: The Bäckegruvan mine site with concentrator and headframe (centre-left in photo) and tailings. Two tailings repositories can be seen; the older tailings adjacent to the lake and a new impounded tailings repository partly covered by vegetation. (Photo: Google earth)



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Table 2: Remaining ore at Riddarhyttan (Mt= million tonnes).

Resources according to data from Fagersta bruk (1978)		Tonnage (Mt)	Fe %	S %	Cu %	Mo %
Known	Bäckegruvan	7.5	32.6	-	-	-
	Bäckegruvan (Cu-rich iron ore)	0.67	29.7	1.0	0.37	-
	Persgruvan	2.8	35.5	-	-	-
Inferred	Riddarhyttfältet	14.5	-	-	-	-



Figure 7: Tailings at Bäckegruvan with concentrator and headframe in the Background. (Photo: Helge Reginiussen)



The tailings at Källfallet was deposited in a lake near the concentrator. The Bäckegruvan concentrator deposited tailings in two repositories, an older one in the Lake Nedre Skärsjön and in a new impoundment that was constructed to the north of the old one (see figure 7). We have estimated, from aerial photographs, that the older repository at Bäckegruvan was used until 1963. The tailings reflect the metal content of the different deposits in the Riddarhytte field, particularly the old tailings at Bäckegruvan that were deposited at a time when the concentrator was less efficient.

3 Analysis of samples

SGU has collected and digitized analyses from older publications and exploration reports (Hallberg & Reginiussen 2019), analyses from the EURARE project data and calculated the production of ore and tailings. In addition, SGU has sampled and analyzed 54 drill core sections from several mines in the area as well as 17 samples from the tailings at Källfallet and Bäckegruvan mines.

Table 3: Analyses of tailings and drillcore from Riddarhyttan.

Analysis of tailings and drillcore		Fe %	S %	Cu %	Mo %	Co %	REE %	As ppm
Tailings ¹	Källfallet (n=8)	7.9–25.2	0.0–0.5	0.01–0.04	0.02–0.05	0.00	0.11–0.48	0–2
	Bäckegruvan, old (n=4)	15.3–23.2	1.5–3.2	0.11–0.32	0.01	0.01–0.11	0.13–0.18	250 ²
	Bäckegruvan, new (n=5)	9.9–18.5	0.8–1.2	0.08–0.12	0.00	0.01–0.02	0.03–0.11	10–70
Drillcore ¹	Bäckegruvan (n=23)	2.05–40.9	0.01–0.69	0.00–0.28	0.00–0.29	0.00–0.02	0.01–1.68	1–250 ²
	Källfallet (n=11)	6.58–42.1	0.02–0.61	0.00	0.00–0.01	0.00	0.01–0.12	0
	Persgruvan (n=20)	8.25–59.3	0.01–1.74	0.00–0.28	0.00–0.01	0.00–0.02	0.01–0.82	0

¹Intervall shows min-max interval.

²250 ppm is upper detection limit.

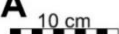


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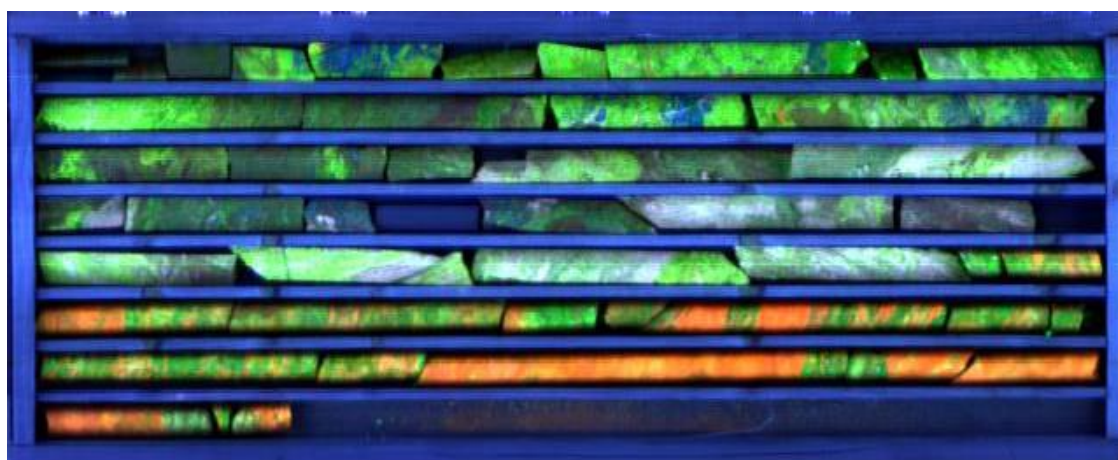


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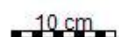


Object: Sweden **BH:** EXTG370 **Box:** 11/11
Interval: 80 - 87.2 / 87.2 **Sensor:** RGB **Type:** RGB Extracted Tray

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B



Object: Sweden **BH:** EXTG370 **Box:** 11/11
Interval: 80 - 87.2 / 87.2 **Sensor:** LWIR (OWL) **Type:** False Colour Composite

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Sveriges geologiska undersökning
Geological Survey of Sweden

Figure 8: Drillcore box containing c. 7.20 meters of drillcore EXTG370 (6634448 /532958) from Bäckgruvan-Bastnäsarten. Red markers show one-meter section interval for chemical analysis yielding for selected elements: Fe=24.47%, REE=1.68%, Cu=0.12%, Ga=41 ppm, Y=460 ppm. Section contains magnetite and minor chalcopyrite and pyrite. **B.** Same drillcore box as in A showing a False Color Composite image that uses data from the longwave infrared (LWIR) part of the infrared spectrum. Magnetite-rich areas render grey-white. The LWIR camera covers the wavelength interval 7500-12000 nanometers (nm) and three infrared bands are rendered in RGB using red= 8611 nm, green = 10022 nm, blue = 11810 nm.



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4 Raw material potential

It seems that the recovery of copper was poor and the content of cobalt and arsenic are high in the old tailings at Bäckegruvan, all four analyses show more than 250 ppm As. The tailings at Källfallet are rich in molybdenum and rare earths, on average 280 ppm Mo and 0.25 % REE.

SGU's calculations indicate that the three sand repositories together contain 7.45 million t of sand with a relatively high content of REE, high copper content in the old tailings at Bäckegruvan and high levels of molybdenum at Källfallet. In total, there are thus 24.5 million tonnes of remaining ore in the closed mines and 7.45 million t of tailings with interesting levels of iron, manganese, copper, cobalt, molybdenum and REE in the area (see Tables 1 and 2). However, it must be emphasized that the number of samples is limited and cannot by no means be compared with the requirements of a compliant ore estimate. Further work is required to be able to report accordance with modern reporting standards



Figure 9: Overview of old tailings at Bäckegruvan. The lake Nedre Skärskön in the background. (Photo: Helge Reginiussen, SGU)



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