SEGF Ronald E. Seavoy Student Field Trip 22:

Base, Precious, and Critical Metal Deposits of the Palaeoproterozoic Skellefte District, Sweden

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On behalf of SFT-2022 participants

The SEG Foundation sponsored the 20th Ronald E. Seavoy Student Field Trip to the world-class volcanogenic massive sulfide (VMS) and gold deposits of the Skellefte district in Sweden. Participants included 18 students from nine countries representing 18 universities, with leaders Rodney Allen, Tobias Bauer, Mac Fjellerad Persson, Nils Jansson, and Patrick Mercier-Langevin and professional mentor Doug Kirwin.

The trip began with a scenic bus journey from the town of Skelleftea westward into the Skellefte district, and the morning was spent settling into our accommodations at the historic Menstrask mine. The site that we stayed was unique in the sense that we ate and met in the building that still hosts the mine shaft (which you can still look down). It was also unique as it is located along the Linbanan (Cableway) between the Boliden and Kristineberg mines, which lie 96 km apart. This cableway carried ore from Kristineberg to the processor in Boliden (Fig. 1).

Fig. 1: Plaque of Boliden-Kistenberg Linbanan

After an introduction to the trip and the geology of the region by Rodney Allen, we headed to the Maurliden Vastra open pit, which closed in 2019. Here we learned from the geochemist Rodrigo Embile, Jr. in charge of remediation of the site what steps they are taking in the permanent closure of the mine site and the restoration of the area. This included a new technique of using “geobags” to store waste rock. The participants were also fortunate enough to see the host rocks to the massive mineralization both in the open-pit walls as well as in outcrops. These outcrops are of quartz-feldspar porphyritic rhyolite pumice deposit, a porous glassy unit that is replaced only a few tens of meters away by massive sulfide.

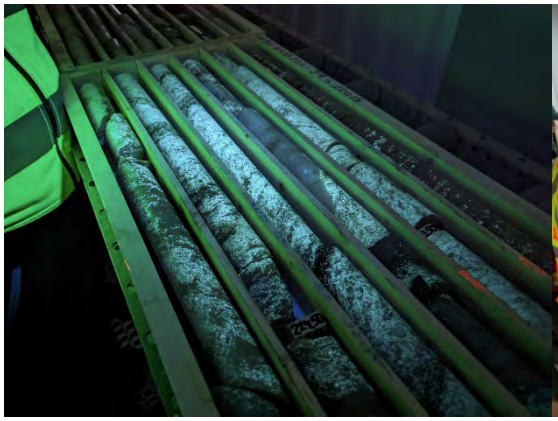
The second day began with exploring the vicinity of the Renstrom mining area in the eastern part of the Skellefte district. Nine outcrop stops were visited in the morning, highlighting the complex stratigraphy and structure of the Renstrom area, which hosts several Zn-, Pb-, Ag-, Cu-, and Au-rich massive sulfide lenses. The Renstrom block is divided by faults and intrusions into several subblocks, each significantly varying in the orientation of bedding. The first outcrop was particularly interesting as it forms part of the andesitic footwall succession directly east of the Renstrom mine (Figs. 2, 3). Here the rocks are weakly altered, just outside of the strong footwall alteration pipe that occurs 100 to 200 m farther to the northeast. The fourth outcrop highlighted the Renstrom-Kyrkvagen volcano-sedimentary stratigraphy, with features such as scours, erosion surfaces, cross bedding, and rounded clasts within the andesitic volcaniclastic rocks. In the afternoon, we visited outcrops in the vicinity of the Petiknas South mine and looked at drill core from the Renstrom and Petiknas South mines in the Boliden core shed, focusing on the hydrothermal alteration, mineralization, and volcanic stratigraphy. The two Zn-Cu-Au Petiknas deposits were among the first blind discoveries in the Skellefte district.

Fig. 2 [left]: Students and field trip leaders peeling back organic cover to observe volcanic outcrop in the Renstrom block.

Fig. 3 [right]: Intense, texturally destructive quartz-sericite-pyrite alteration zone in the footwall of the Renstrom VMS system.

Day three was an exciting day spent at the Kristineberg mine, likely the first-ever deposit discovered using electromagnetic (EM) surveying in 1918 and in production since the 1940s. Our group was lucky enough to visit the underground mine, 900 m below ground level, and look at the core of the

new Ravliden North discovery under the good care of Erik Bjänndal, Peter Erikson, and Helen Thomas. In the evening we had the chance of having Rolf Jonsson, former exploration manager at Boliden, explaining the history of the district and how key discoveries were made.



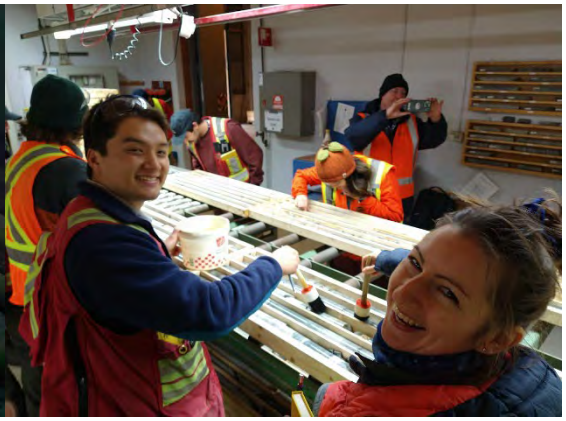


Fig. 4 [left]: Andalusite fluorescing under UV light in drill core, extracted from below the massive sulfide mineralization.
Fig. 5 [right]: Two of the authors inspecting drill core!

On day four, participants were taken to the Boliden area to visit the core shed and processing plant. The Boliden Au-Cu-As deposit (8.3 Mt at 15.9 g/t Au, 50 g/t Ag, 1.42 wt % Cu, 0.9 wt % Zn, 0.3 wt % Pb, and 6.8 wt % As) was discovered in 1924 and mined from 1925 to 1966. As a gold-rich VMS deposit, hosted in a complex succession of volcanic rocks of the Skellefte and overlying Vargfors groups, it ranks as the second richest and one of the largest in the world. Locally, it is the fifth largest massive sulfide deposit of the Skellefte district, and it was the largest European gold producer for a significant part of the 20th century.

The morning was spent happily inspecting the drill core from two magnificent holes (Figs. 6, 7). The first hole was from the center of the Boliden deposit itself, showcasing spectacular intersections of the ore zones and some of the proximal metamorphosed sericite-silica-pyrite alteration. The mineralization at Boliden consists of highly strained massive pyrite lenses that contain bodies (a few meters to a few tens of meters wide) of gold-rich arsenopyrite ore. This ultrafine-grained massive arsenopyrite was extraordinary; it resembled steel, fractured conchoidally, and carried very high grades (~60 g/t Au). The second drill core was the discovery hole of the Strömfors deposit, drilled in 2019 and located 4 km northeast of the Boliden processing plant. The Strömfors deposit is a polymetallic VMS deposit, with sphalerite, pyrrhotite, galena, arsenopyrite, and sulfosalts as the main mineral assemblage. This hole showcased part of the Ronja lens, which is the richest part of the VMS mineralized system. An insightful talk about how the Strömfors deposit was discovered (follow the synvolcanic faults!) was given that evening by geologist Jonas Möller Lasskogen.

Fig. 6 [Left]: Ultrafine-grained, high-grade Au arsenopyrite that has behaved in a brittle manner, with fractures infilled with chalcopyrite and pyrite, Boliden ore. BOL-24 core.

Fig. 7 [Right]: Red (Fe-rich) sphalerite, pyrite, pyrrhotite, arsenopyrite, galena ± sulfosalt mineralization of the Ronja lens, Strömfors deposit.

After lunch in the unbelievably beautiful Boliden canteen, an overview of the Boliden processing plant was given by Lisa Malm and Anna Gulkova. Lisa explained how the Boliden mill processes the different ores from the Kristineberg, Kankberg, and Renström mines to produce Cu, Zn, and Pb concentrates, doré (Au-Ag) bars, and Te cement. It was fascinating to listen to Lisa explain how each of the ores must be treated differently owing to their individual properties, such as hardness, mineralogy, and contained metals, to maximize the recovery of each product. We then got to experience the journey of these ores with a tour around the plant, equipped with full PPE and headphones so we could all hear Lisa explain each part of the process (Fig. 8).

Fig. 8: Field trip participants, enjoying looking a little like Minions, gather for a photo before the amazing tour around the Boliden processing plant tour by manager Lisa Malm (third from right). Photo courtesy of Doug Kirwin.

On day five we first visited the Björkdal gold deposit, owned and operated by Mandalay Resources, and the second largest gold deposit after Boliden (35.2 Mt at 1.35 g/t Au). Sam Miller (exploration manager) and Javier Santa Barbara (resource geologist) gave a great overview of the complex geology and operations of the open pit and underground mine. The free gold is structurally associated with conjugate NE- to E-trending quartz veins, which vary in thickness from a few cm to a meter, interpreted as third-order structures formed in association with regional N- to NW-striking thrust faults. The intricate vein system makes block modeling and wireframing tricky and is associated with the NW-dipping contact between volcano-sedimentary rocks and a marble unit of the Skellefte Group. A visit to the open pit allowed us to view the contact, and participants enjoyed looking for hand samples with visible gold—some of us even got lucky! A visit to the core shed followed, where we saw gold mineralization associated with pyrite, chalcopyrite, pyrrhotite, galena,

tourmaline, scheelite, and tellurides. The scheelite was observed using a UV lamp, and it fluoresced a beautiful sky blue!

The afternoon included a wonderful al fresco BBQ lunch in the forest and a visit to the Varutrask pegmatite mine. The Varutrask pegmatite is significantly Li and Cs bearing. The discovery of the Varutrask pegmatite deposit occurred in 1932 by Harald Holmgren and was eventually bought by Boliden AB in 1936, remaining in operation until 1946. The students had the opportunity to do a complete tour around the mine, guided by the instructors who highlighted a beautiful array of minerals, including lepidolite and tourmaline (Figs. 9, 10).

Fig. 9 [left]: Lepidolite (Li-bearing mica ~2 cm crystals).
Fig. 10 [right]: Green tourmaline crystals, approximately 3–5 cm in length.

It goes without saying that as well as experiencing all the fabulous VMS geology, lifetime friendships between the group members were forged, and we all look forward to seeing each other again around the world. On behalf of the group, we would like to thank our field trip leaders, industry participants, and the management at Boliden AB and Mandalay Resources for organizing this exceptional opportunity and for providing excellent tours and explanations of the vast mining operations taking place. A special thank you to Mac Fjellerad Persson, the man who made a lot of it happen behind the scenes! Finally, thank you to the Society of Economic Geologists Foundation for funding these student trips and for educating future generations of economic geologists.