Hydrothermal alteration, 3D modeling, and sheath folding at the volcanic-hosted Falun Zn-Pb-Cu-(Au-Ag) deposit: Implications for exploration in a 1.9 Ga ore district, Fennoscandian Shield, central Sweden*

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The Paleoproterozoic (1.9 Ga), volcanic-hosted Zn-Pb-Cu-(Au-Ag) sulfide deposit at Falun is located in the Bergslagen lithotectonic unit, central Sweden, which includes one of the major ore districts in the Fennoscandian Shield, northern Europe. The Falun deposit is known mainly as one of the world’s leading copper suppliers over many centuries. During the 20th century, the mine was a major base (Zn, Pb, Cu) and precious (Ag, Au) metal producer until it closed during 1992.

This study has the following four aims: (i) Identify the style and spatial distribution of hydrothermal alteration; (ii) determine the geometry of the different types of ore bodies; (iii) provide a mechanism for the structure of the deposit; and (iv) address broader implications for the Bergslagen ore district. Petrographic and structural data were collected during surface mapping and microscope work; modeling of the different ore bodies in 3D space was completed using available mine level maps and data collected during new logging of available drill cores.

The Falun deposit is affected by polyphase ductile deformation and metamorphism under amphibolite facies conditions. The metamorphosed alteration rocks are dominated by distal quartz-mica-cordierite-(anthophyllite) and proximal quartz-anthophyllite assemblages, interpreted to represent Si-, Fe-, Mg-metasomatism of felsic volcanic rocks. Dolomite and calc-silicate (tremolite, actinolite, diopside)-skarn assemblages are interpreted as the equivalent alteration of carbonate rocks. Surface mapping in the open pit indicates that the ore bodies are completely enveloped by these altered rocks.

Structural data suggest the presence of a reclined F2 fold that plunges steeply to the southeast, with a stretching component defined by a linear grain-shape fabric sub-parallel to the fold axis. Modeling in 3D space reveals the presence of several rod-shaped ore bodies that also plunge steeply to the southeast and thicken and merge upwards into a single ore body that is up to 270 m in diameter at the ground surface. The ore body close to this surface is zoned in a concentric pattern, from a massive, pyritic Zn-Pb-Cu-sulfide core in the inner part to a more Cu-rich sulfide zone and then a semi-massive to disseminated Cu-Au mineralization in the outer part. The cone-shaped and zoned ore bodies are interpreted as steeply-plunging megascopic sheath folds, formed in a ductile, high-strain tectonic regime. The viscosity contrast between competent, strongly silicified and metamorphosed felsic volcanic host rock and softer massive sulfide ore is suggested to have enhanced the development of these sheath folds.
Steeply plunging, rod-shape geometries have commonly been reported for several volcanic-hosted sulfide and Fe oxide ore deposits in the Bergslagen lithotectonic unit and megascopic sheath folds have been identified in a high-strain belt in the northern part of this unit. If sheath fold formation can be confirmed as a key deformation mechanism for ore bodies in this mineral district, in contrast to the classical model of dome and basin fold interference structure, this will influence near-mine exploration strategies. Previous structural concepts and models for footwall/hanging wall relationships will need radical revision and areas previously considered as barren hanging wall lithologies may have a higher exploration potential.