GEOCHEMICAL CHARACTERIZATION OF THE BACK FORTY VOLCANOGENIC MASSIVE SULFIDE DEPOSIT IN MENOMINEE COUNTY, MICHIGAN

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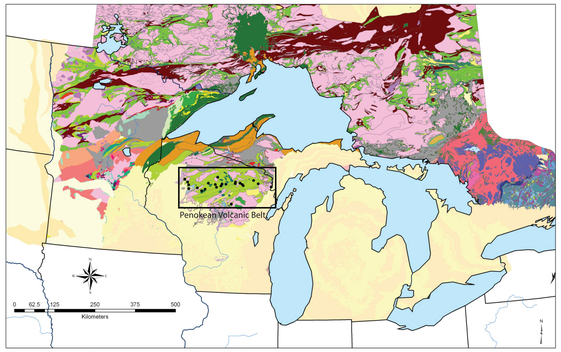
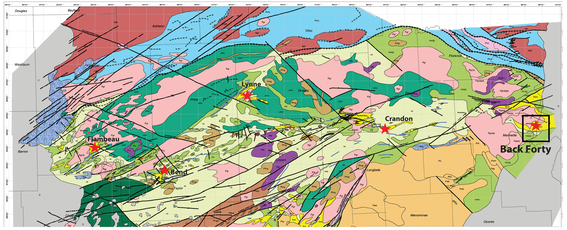


Fig. 1. Bedrock Geology of the Lake Superior Province and the location of the Penokean Volcanic Belt

The Back Forty volcanogenic massive sulfide (VMS) deposit, located in Menominee County, Michigan is a Paleoproterozoic (1874 ± 4 Ma; Schulz et al., 2007) polymetallic ore deposit which formed during the Penokean Orogeny. Back Forty belongs to a large group of VMS deposits (e.g. Crandon, Flambeau) located in the Ladysmith-Rhinelander greenstone belt which is primarily composed of island arc volcanic and intrusive rocks (Schulz and Cannon, 2007). The nature of mineralization at Back Forty is similar to the bimodal felsic-dominated Kuroko-type VMS deposit model (Barrie, 2007) and the ore minerals are primarily hosted in rhyolitic rocks which appear to be related to deeper plutons of granite and tonalite with adjacent mixtures of mafic volcanic rocks along with tuffaceous and argillaceous sedimentary sequences. The mineralization consists of massive, semi-massive and stringer sulfide zones along with sulfide-poor Au and Ag enriched zones. It has been estimated that there are 15.13 million measured and indicated tonnes of ore minerals with average grades of 2.03 ppm Au, 24.28 ppm Ag, 3.06% Zn, 0.33% Cu and 0.22% Pb.

Structurally, the Back Forty deposit and its host rocks have been folded into a west-southwest striking, southwest plunging, asymmetric anticline (Fig. 9). Five mineralized zones have been identified (Figs. 7 and 9): the Main Zone, the East Zone, the Pinwheel Zone, the Tuff Zone and the Stringer Zone. The host rocks are mostly composed of chloritized, sericitized and silicified rhyolites and fragmental tuffs frequently alternating with fine-grained ash-tuff layers and laminated tuffaceous sediments. The tuff layers are mostly comprised of coarse grained, quartz-feldspar phyric, rhyolitic to rhyodacitic lapilli tuff with crystal fragments and breccias (Ross et al., 2011) as shown in Figure 10. The host rocks have been intruded by a late dacitic quartz-feldspar porphyry (QFP; Fig. 11).



Major VMS Deposits in Penokean Volcanic Belt

Crandon	67 million tonnes	5.6% Zn, 1.04% Cu, 1.1 g/t Au, 39 g/t Ag
Lynne	5.6 million tonnes	9.27% Zn, .47% Cu, .7 g/t Au, 74 g/t Ag
Flambeau	5.8 million tonnes 1.9 million tonnes	4.0% Cu, 1.7 g/t Au, 31 g/t Ag 10.5% Cu, 3.4 g/t Au, 69 g/t Ag
Bend	3.5 million tonnes	1.9% Cu, 2.8 g/t Au, 12 g/t Ag
Back Forty	15.1 million tonnes	3.0% Zn, 2.0g/t Au, 24 g/t Ag, 0.3 % Cu

Fig. 2. Bedrock geology of the Penokean Volcanic Belt and the locations of major VMS deposits in northern Wisconsin and Michigan.

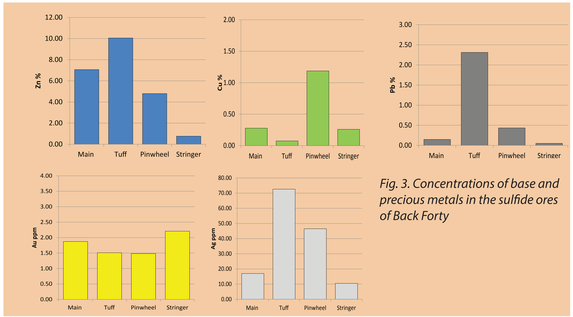
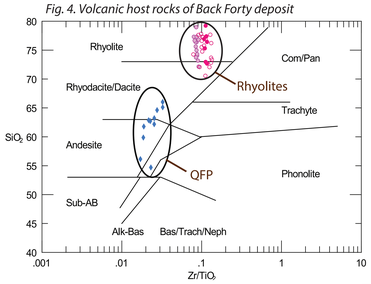


Fig. 3. Concentrations of base and precious metals in the sulfide ores of Back Forty

Fig. 4. Volcanic host rocks of Back Forty deposit



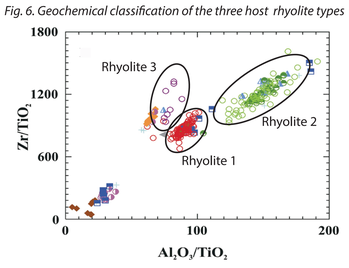


Fig. 6. Geochemical classification of the three host rhyolite types

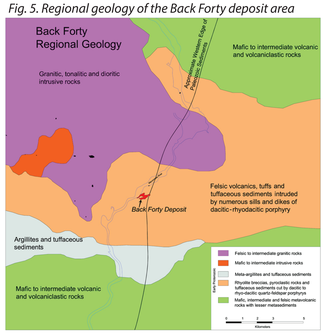


Fig. 5. Regional geology of the Back Forty deposit area

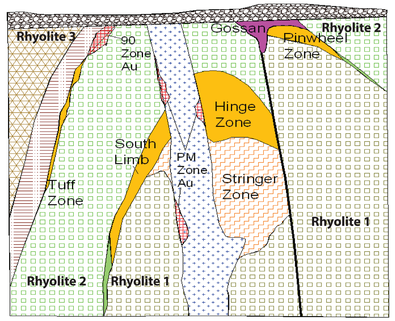


Fig. 7. Vertical cross section of the host rocks of the Back Forty deposit

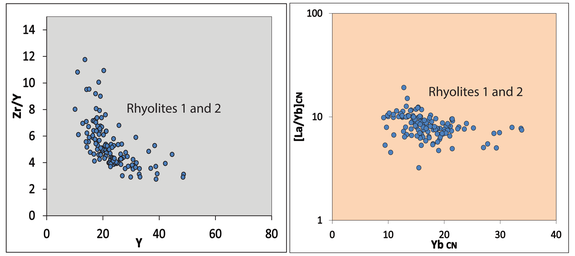
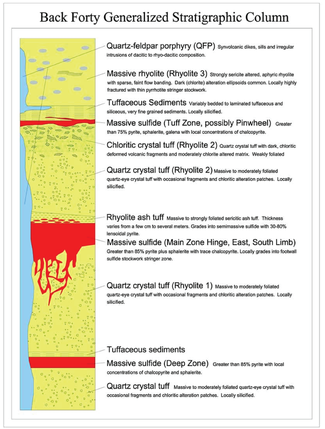


Fig. 8. Trace element plots for host rock rhyolites 1 and 2, after Hart et al. (2004) and Baboury and Pearson (2008).

Three chemically distinct varieties of rhyolitic rocks have been identified based on trace element characteristics (Fig. 6; Quigley et al., 2008) out of which two are found to host the sulfide mineralization. With moderate Zr/Y ratios, intermediate HFSE concentrations and moderately fractionated REE patterns, the host rock rhyolites represent calc-alkaline chemical affinities (Fig. 8).

Massive sulfide ore horizons at Back Forty include pyrite, sphalerite, chalcopyrite and galena with variable amounts of Au and Ag and minor amounts of pyrrhotite and arsenopyrite. The upper levels of the deposit, close to the surface, are characterized by two oxidized iron-rich gossans which consist principally of hematite, goethite with significant amounts of Au, Ag and minor amounts of electrum, bornite, argentite and other minerals. In general, the relatively higher abundances of Au and Ag in Back Forty, when compared with other VMS deposits, indicate higher concentrations of Au and Ag in the mineralizing fluid or processes of metallic redistribution by late hydrothermal solutions.



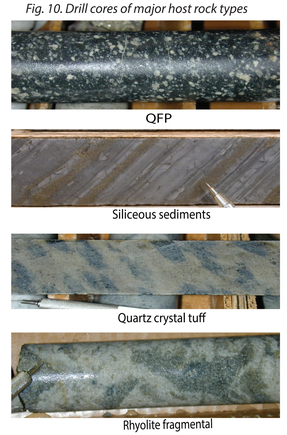


Fig. 10. Drill cores of major host rock types

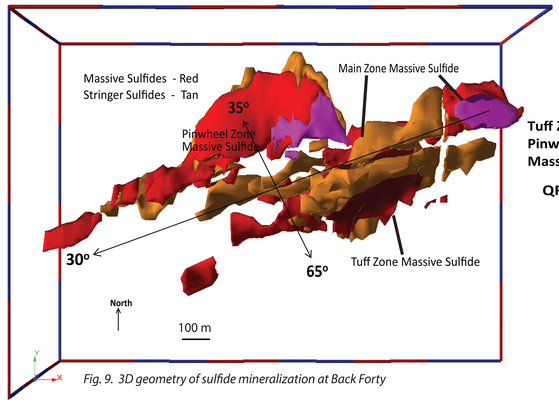


Fig. 9. 3D geometry of sulfide mineralization at Back Forty

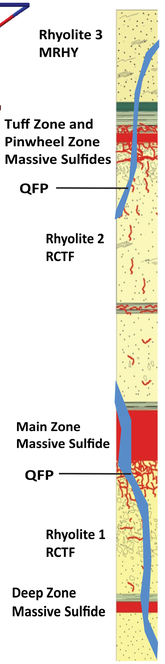


Fig. 11. Location of samples of massive, semi-massive and stringer sulfide horizons and the intrusive relation of the quartz-feldspar porphyry

From the observed surficial oxidation in the gosan it is evident that sulfides were lost with the formation of sulfuric acid and were replaced by iron oxides. Au and Ag most likely transported as chloride or sulfur complexes in oxidized hydro-thermal fluids and were precipitated as native metals along with iron oxides.

References

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