

0. EXECUTIVE SUMMARY

The data and findings in this research report have been and will continue to be used to support the environmental review and mine permitting responsibilities of the Minnesota DNR. The information contained in this report is particularly useful for operations that are or may excavate rock from the Duluth Complex (DC) and Virginia Formation (VF). These regulatory activities require prediction of solute release from waste rock during mine operation and in the decades and centuries following mine closure. As a foundation for such predictions, the reactions occurring in waste rock (stockpiles, pit walls) and variables affecting these reactions must be understood. In the present project, laboratory studies were conducted for eleven years to examine solute release and variables affecting this release from VF waste rock.

The objectives of this report are to 1) characterize the solid phase composition and evaluate the drainage quality observed for the VF samples under test by the DNR, 2) compare the results from objective 1 to existing data sets from Northshore Mining (NSM) and PolyMet Mining (PM) tests of VF samples with similar sulfur content, and 3) compare the DNR VF data to the DC waste rock data set under test by the DNR.

Since 2004 the DNR has had five samples of VF drill core from NSM under kinetic test. These samples range in sulfur content from 0.22 to 0.81 and consist primarily of plagioclase, quartz, cordierite, biotite, and augite. Minimum leachate pH was typically in the range of 4.0 to 6.4 and tended to decrease with increasing sulfur content. Sulfate and major cation release rates tended to increase as a function of sulfur content. One exception to this was the 0.30%S sample which tended to have release rates lower than anticipated. Metal concentrations (Cu, Ni, Co, Zn) were analyzed less frequently over the eleven year period of record, however these data show a similar increasing trend with sulfur content.

The chemical composition and mineralogy of the DNR and NSM VF samples were fairly similar. However, drainage quality differed considerably between the two sample sets. Minimum drainage pH from the NSM samples was typically 0.5 to 1.5 units lower than the DNR samples. As a result, the NSM samples had sulfate release rates that were, on average, 1.3 to 2.6 times higher than the DNR samples. Likewise, copper and cobalt release rates in the NSM samples were, on average, 3 to 30 times higher than the DNR samples.

The DNR VF samples were also compared to the VF samples under test by PM. Chemical composition between these two samples sets was somewhat similar, however the mineralogy was very different. The PM samples consisted primarily of clinopyroxene, potassium feldspar, and mica. Minimum drainage pH from the DNR samples was typically 1 to 2 units lower than the PM samples. As a result, sulfate release rates were, on average, 3 to 5 times higher than the PM samples. In addition, peak copper and cobalt release rates in the DNR samples were as much as 250 to 700 times higher than the PM samples.

The DNR VF samples were also compared to the Duluth Complex waste rock (DCWR) samples with similar sulfur content under test by the DNR. Because these samples were from two distinctly different rock types, chemical composition, mineralogy and drainage quality were significantly different. Minimum drainage pH in the VF samples was typically 1 unit lower than

the DCWR samples. As a result, sulfate release rates in the VF samples were, on average, 2.5 times higher than the DCWR samples. Copper release in the DCWR samples, on average, was 13% higher than the VF samples. However, cobalt release in the VF samples, on average, was 44% higher than the DCWR samples. These differences in release rates were not reflective of the chemical compositions and may have had more to do with the sulfide minerals present in these samples.

These types of comparisons emphasize the importance of performing a thorough waste rock characterization program during environmental review and permitting. These programs should include all rock types that may be disturbed during mineral resource development of the DC and VF.