**ARD Executive Summary**

This paper presents an overview of potential geochemical environmental issues associated with a proposed non-ferrous underground mine for copper (Cu), nickel (Ni), cobalt (Co) and platinum group elements (PGEs). The proposed Twin Metals Minnesota Project (TMM Project) targets the Maturi Deposit within the Duluth Complex in northeast Minnesota near Ely. The potential geochemical environmental issue of most concern for non-ferrous mining is the generation of acid rock drainage (ARD) and associated metal leaching (ML), commonly combined using the acronym ARD/ML. The process of ARD generation is very well understood, as are the engineering options available to prevent, minimize, and mitigate ARD formation. Based on all geochemical information generated to date, the long-term potential for ARD generation for the TMM Project is considered low to non-existent.

**Acid Rock Drainage and Metal Leaching - State-of-Practice**

Research into the process of ARD formation and methods to minimize its impacts has been conducted worldwide for more than 50 years. Much progress has been made in the last 20 years through a number of research organizations, government agencies and industry consortiums. The Global Acid Rock Drainage Guide (GARD Guide), which is sponsored by the International Network for Acid Prevention (INAP), consolidates state-of-practice information on the prediction, prevention and management of ARD. The GARD Guide represents a collaborative effort by many experts in the field of ARD. Specific contributors and advisors to the GARD Guide include representatives from the mining industry (including TMM), academia, private consulting, and government agencies from around the world. The widespread and global use and referencing of the guide are an indication of its acceptance and credibility.

ARD is formed by the natural oxidation of sulfide minerals when exposed to air and water. In general, the ARD risk associated with an ore deposit is proportional to the amount of sulfides present and inversely proportional to the amount of neutralization potential available. For the same deposit type, sulfide mineralogy and concentrations, and thus ARD potential, can be highly variable. Therefore, it is important to assess, design and plan mining projects on a site-by-site basis.

**Northeast Minnesota’s Duluth Complex Mineral Deposit**

The Maturi Deposit, located within the larger Duluth Complex in northeast Minnesota, is a magmatic sulfide deposit. It is one of the world’s largest undeveloped copper-nickel deposits. Unlike many other types of ore deposits, the sulfide minerals in these deposits are directly associated with and generally restricted to the ore, thereby limiting the potential for the generation of potentially acid generating (PAG) waste materials.

Considerable information is available regarding the environmental behavior of the Duluth Complex. Studies of the ARD potential of Duluth Complex rocks have been conducted at the laboratory and field scale by U.S. government research organizations and private industry. The information available from these studies provides a fundamental understanding of the expected environmental behavior of the materials originating from the TMM Project. To add to this understanding, TMM has implemented a comprehensive Mine Material Characterization Program (MMCP) aimed at determining the geochemical behavior of Project-specific mine materials, including waste rock, ore, and tailings. This program has been developed in cooperation with the Minnesota Department of Natural Resources (MDNR). TMM’s commitment to comprehensive characterization of the geochemical behavior of the Maturi Deposit began during exploration drilling and continues today, for a total duration of almost one decade.

The ARD potential of mine materials is determined by the balance between the acid generation potential (AP) of a material (i.e. sulfide concentration) and the neutralization potential (NP). The sources of AP and NP in Duluth Complex rock are well understood.

Geochemical characterization of Duluth Complex rocks by TMM and others has indicated that total sulfur content and sulfide mineralogy are the controlling factors in the rate and severity of ARD generation. Sulfide mineralization within the Maturi Deposit comprises copper, nickel and iron sulfides. Iron sulfides (e.g., pyrite and pyrrhotite) typically are the most common source of ARD due to their high reactivity, but their abundance in the Maturi Deposit is lower than the copper and nickel sulfides. The copper sulfide chalcopyrite, the most abundant sulfide mineral in the Maturi Deposit, oxidizes at a slower rate than the iron sulfides and may not generate acid upon oxidation. As such, the potential for ARD generation of the Maturi Deposit due to sulfide oxidation is much lower than many other types of deposits containing sulfide minerals.

Silicate minerals are the primary source of NP in Duluth Complex rocks. Silicate mineral NP is sufficient to maintain circum-neutral pH conditions for extended periods for rock with a low total sulfur content. For material with higher total sulfur contents, silicate NP is responsible for a delay in the development of acidic conditions, thereby allowing time for implementation of appropriate engineering controls. The lag time to ARD is also related to sulfur content (i.e. lag time decreases as sulfur content increases).

TMM's characterization program includes both short-term and long-term testing (i.e. static and kinetic tests, respectively). In addition to the evaluation of ARD potential, the testing program provides information to evaluate sulfate and metal leaching from mine materials. These data support the development of mine water quality estimates, a multi-disciplinary effort which includes consideration of many other factors (e.g., water balance, physical characteristics of potential source materials, baseline water quality, geochemical conditions in the receiving environment, etc.).

A comprehensive understanding of the geochemical behavior of mine materials is fundamental to the prediction and prevention of possible impacts to the receiving environment. The extensive geochemical dataset and deep understanding of the behavior of Duluth Complex rocks result in confidence in the prediction of potential environmental impacts and selection of effective engineering controls.

**Twin Metals Minnesota Project Design**

Prevention of ARD/ML starts at exploration and continues throughout the mine-life cycle. The GARD Guide presents methods for prevention of ARD/ML throughout the mine-life cycle, many of which have been incorporated into the TMM Project design. TMM's strategy to mine material management focuses first on elimination of ARD/ML risk, with engineering controls as a secondary or complementary action. Key aspects of TMM's waste management plan include minimizing the mass, sulfur content and exposure of any sulfidic material mined and brought to surface. The environmentally focused mine design has eliminated the features which are most often the cause of long-term ARD/ML issues at other mine sites:

- **No Open Pit**: Resource development would be by underground mining as opposed to open pit. The environmental benefits of underground mining, as compared to an open pit, include reduced land disturbance and waste generation and the avoidance of a pit lake or other large surface feature at closure.
- **No Waste Rock Stockpiles**: During operations, all waste rock would remain underground as backfill. The Project would not generate any permanent or even long-term surface stockpiles.

- **No High-Sulfur Tailings:** By design, because virtually all of the sulfide minerals are removed in the concentration process, the sulfur content of the tailings would be low (≤0.2%), which is below the threshold identified for acid generation. Storage in a dry stack facility, as opposed to a traditional slurry impoundment, is current industry best practice.

The proposed engineered environment contains the following features:

- Surface:
  - **Tailings:** The sulfur content of the tailings is very low as virtually all sulfur reports to the concentrates. As such, the tailings are classified as having a low to non-existent potential to generate ARD. Approximately sixty percent of the tailings would be dewatered and compacted in a dry stack facility which would be covered and progressively reclaimed with native soil and vegetation as the project progresses. In addition to the very low sulfur content, tailings management, which includes compaction and progressive reclamation, limits exposure of the tailings to air and water. Use of a dry stack reduces ground disturbance relative to traditional slurry impoundments, eliminates the need for water-retaining structures such as dams, and significantly diminishes draindown from the tailings mass relative to a tailings slurry.
  - **Waste Rock**: During construction and the first two years of operations, there would be minimal and temporary storage of waste rock and ore on the surface in a lined facility (approximately one million tonnes for less than four years). This duration is less than the anticipated lag time to acid generation for most waste rock that is generated during the early years of operation. During the short period of storage on surface, all contact water would be captured. All waste rock on surface would be processed though the concentrator within the first two years of operations. Therefore, there would be no long-term storage of waste rock on surface.
  - **Water Management**: All surficial contact water would be captured to prevent its discharge to the environment.
- Underground:
  - During operation, underground water would be collected and used in the process.
  - Waste rock would remain underground during operation and there would be no surficial waste rock facilities after closure.
  - All waste rock, with the exception of the waste rock brought to surface during the construction period, and a portion of the tailings (approximately 40%) would be used for underground backfill. Binder would be added for geotechnical purposes, but would also represent a source of additional alkalinity and buffering. Waste rock backfilled in the stopes would be encapsulated in cemented tailings, thereby minimizing exposure of any sulfidic rock to oxygen.
  - Flooding of the underground mine following cessation of mining activities would virtually eliminate sulfide oxidation.
- The modern regulatory environment requires more than a hundred local, state and federal environmental permits to plan, construct, operate, and close the proposed underground mine. This high level of scrutiny ensures the use of proven, state-of-the-art practices.