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Written Testimony on “Examining the Mineral Wealth of Northern Minnesota”

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Introduction

Mineral deposits are formed as end products of a wide variety of Earth processes and reflect, in essence, a tapestry of time, processes, and geologic terranes. Geologists have long used such knowledge to target exploration programs for specific ore deposit types/commodities within different geologic terranes. Any coherent examination of the vast mineral wealth of Northern Minnesota must begin with an understanding of the geology of the Lake Superior region and how specific profound global geological events in Earth history set the stage for the unique set of world-class mineral resources found therein.

My 35+ years as an economic geologist have primarily been spent out in the field unraveling the geology and mineral potential of the Precambrian rocks of Northern Minnesota. My Ph.D. from the University of Minnesota focused on the gold and copper-zinc mineral potential of a large area of Archean granite-greenstone terrane north of the Mesabi Range. I have worked extensively as an academic researcher and as the Senior Vice President of Exploration for Duluth Metals on understanding the geology and Cu-Ni-Co-PGE mineralization of contact-type deposits of the Duluth Complex. My two seasons of field research on seemingly 100% exposure of mafic intrusions in the McMurdo Dry Valleys of Antarctica, that are similar to the intrusions in the Duluth Complex, has led to a profound new understanding of how these mineral systems work and form world-class ore deposits of critically important minerals. I have recently been a Ph.D. committee member for a University of Michigan student studying the origin of the Ti-Fe-V ores of the Longnose and TiTac deposits along the western margin of the Duluth Complex. I have completed academic research studies on the eastern-most Mesabi Range, defining coherent zones of iron ores at Dunka Pit that perhaps one day could be mined to make DRI-grade (very-low silica) taconite pellets, and am currently actively engaged at Big Rock Exploration in a drilling program for manganese resources within the Emily Deposit of the Cuyuna Range.

It is these unique rocks and their known and potential mineral wealth that is the focus of today’s hearing, and I am happy to share my knowledge to the committee. This written testimony will attempt, in general terms, to explain how Northern Minnesota’s known mineral resources, including Fe-Mn deposits within the states iron ranges and copper-nickel-cobalt-platinum group element (Cu-Ni-Co-PGE) & titanium-iron-vanadium (Ti-Fe-V) deposits in the Duluth Complex, are the outcomes of specific geological events unique to the Lake Superior region.

Geology of Northern Minnesota

Minnesota is situated at the southern edge of the Canadian Shield, the nucleus of the North American continent that formed during Precambrian time. This period of time encompasses about 85% of Earth's history, beginning with the formation of planet Earth about 4.550 billion years (Ga) ago and ending about 0.54 Ga, when organisms with hard parts, such as shells, rapidly diversified. The great span of Precambrian time is divided for convenience into two major parts—the Archean Eon (4.55-2.50 Ga) and the Proterozoic Eon (2.50-0.54 Ga). The rocks formed in Minnesota during this enormous span of time record a complicated geologic history that involved volcanoes, ocean islands, mountain chains, earthquakes, and eons of time where the landscape simply weathered and eroded away.

As the various mountainous Precambrian landscapes of Minnesota were slowly eroded to low relief over 2.7 billion years, Precambrian rocks that were once much deeper within the Earth are now exposed on the surface in Minnesota's flat terrain. These rocks record processes and conditions that existed beneath landscapes long since removed by erosion. Presently, the deeply eroded Precambrian rocks of Northern Minnesota are mostly covered by a veneer of glacially deposited clay, silt, sand, and gravel.

Archean 2.7 Ga Rocks of Northern Minnesota

The Archean rocks of Minnesota are part of the Superior Province of the Canadian Shield. The Superior Province is subdivided into subprovinces, which are broadly east–west, linear belts of rocks of similar geologic history and age. The subprovinces in Minnesota from south to north include the Minnesota River Valley, Abitibi-Wawa, Quetico, and Wabigoon.

The ~2.7 Ga Archean rocks of Northern Minnesota occur mainly north of the Mesabi iron range, and may be seen in Voyageurs National Park, in the western part of the Boundary Waters Canoe Area Wilderness, and in scattered areas elsewhere between International Falls and Ely. This group includes the Abitibi-Wawa granite-greenstone subprovince, the Quetico subprovince, and the Wabigoon granite-greenstone subprovince. The Abitibi-Wawa and Wabigoon subprovinces originally were parts of volcanic chains that were later deformed and intruded by granite. The Quetico subprovince was likely a large sedimentary basin on or between the volcanic arcs of the Wabigoon and Abitibi-Wawa. The granites welded the greenstone belts together to form the core of the North American continent. The end of the Archean Eon is a profound time in Earth history. The formation of stable cratonic cores of continents allowed for the deposition of vast sequences of sedimentary rocks. World-wide, Archean greenstone terranes are known to host some of the largest mineral deposits on Earth, especially iron, orogenic gold, and copper-zinc-rich volcanogenic massive sulfide deposits.

Paleoproterozoic 1.9 – 1.7 Ga Rocks of Northern Minnesota

One of the most profound events in Earth's history is recorded in the Paleoproterozoic rocks of Northern Minnesota. That event was the proliferation of cyanobacterial life on Earth in shallow water oceanic settings at the margins of eroded Archean cratons. This ancient life, which is recorded in the rocks as fossil stromatolites, released oxygen into the Earth's oceans and atmosphere and thus precipitated vast quantities of dissolved iron out of the ocean to form the chemical sedimentary rocks we call iron formation. Paleoproterozoic rocks occur in Minnesota from St. Cloud northeast to Moose Lake and Carlton, and north up to the Mesabi Iron Range near Eveleth and Hibbing. The southern part of the Paleoproterozoic terrane, approximately south of a line that runs west from Jay Cooke State Park, is a mixture of metamorphosed sedimentary and volcanic rocks and includes the Fe-Mn ore deposits of the Cuyuna iron range. To the south, these rocks were intruded later by several large granitic intrusions, emplaced between 1.80 and 1.76 Ga, that collectively form an amalgamation referred to as the East-Central Minnesota batholith.

The northern part of this terrane is made up of slate and graywacke, iron formation, and quartzite. The base of this sequence is quartzite, formerly sandstone, that was deposited on top of the older Archean bedrock. Above the quartzite is the Biwabik Iron Formation, long mined for its vast quantities of iron ore. Slate and graywacke overly the iron formation and covers a vast area from the Mesabi Iron Range south to Jay Cooke State Park, where one can easily see that it has been folded and deformed.

The metamorphosed volcanic and sedimentary rocks that make up the southern part of the Paleoproterozoic terrane are likely part of a former mountain belt, the Penokean orogen, that extended west from Lake Huron to South Dakota, and perhaps farther, from about 2.0 to 1.8 Ga ago. The eroded remnants of this belt have geologic similarities to modern mountain belts along the west coast of North America. Therefore, geologists infer that mountainous terranes comparable to those currently found in western California existed long ago in Minnesota. During this mountain forming orogenic event, the crust was uplifted, and a large basin formed to the north; sediment shed into this northern segment produced the thick sequence of slate and graywacke in the deeper parts, and along the northern margin of this basin, the Pokegama Quartzite and Biwabik Iron Formation were deposited forming the Mesabi Iron Range, one of the largest mining districts in the world. In 2019, the Paleoproterozoic age iron deposits of the Lake Superior region (Northern Minnesota and Michigan) accounted for 98% of the usable iron-ore products in the United States.

Mesoproterozoic 1.1 Ga Rocks of Northern Minnesota

Mesoproterozoic rocks of Northern Minnesota occur along the shore of Lake Superior, continue south along the Minnesota–Wisconsin border, and extend southwest into Kansas. These rocks formed around 1.1 Ga ago along the Midcontinent Rift system, a major feature that formed by the spreading apart of older continental crust. As the crust spread and thinned, fractures and faults formed, providing pathways for molten magma from the mantle to work its way to the surface, where it erupted as volcanoes. The base of the volcanic pile was intruded by magma that cooled more slowly below the surface, forming troctolite, gabbro, anorthosite, and granite. The wholesale partial melting of the Earth's mantle, and transfer of these magmas upwards into the Earth's crust, is the reason why Northern Minnesota hosts enormous quantities of critical minerals associated with the Mid-Continent Rift. Essentially every atom of copper, nickel, cobalt, platinum, palladium, gold, silver, titanium, vanadium, and iron known to exist in Mesoproterozoic age ore deposits of Northern Minnesota were transferred by buoyant magmas from the Earth's mantle to crust by these magmas. When volcanism ceased, blankets of sand, now sandstone, were deposited in a basin on top of the volcanic rocks, such as the Hinckley Sandstone exposed in Banning State Park.

Rocks similar to the Mesoproterozoic volcanic rocks exposed along the north shore of Lake Superior were mined extensively for copper in Michigan, but no similar deposits of economic scale have been found here. In Minnesota, an enormous reserve of copper, nickel, cobalt and associated platinum, palladium, and gold exists at the base of the Duluth Complex, along the northwest edge of the Mesoproterozoic system, and in an intrusion near the town of Tamarack. The sandstones that overlie the volcanic rocks have been quarried in the past for building and paving stone, and gabbro and anorthosite is quarried for both dimension stone and road aggregates.

Mineral Resources of Northern Minnesota

Since the 1880s, two broad types of mineral resources have been actively mined and/or explored for in northern Minnesota. They are: ***1) Ferrous resources,*** which include iron (Fe) deposits of the Archean 2.7 (Ga) Vermilion Range, the Paleoproterozoic 1.85 Ga Fe deposits of the Mesabi Range, and manganese-iron (Mn-Fe) deposits of the Cuyuna Range; and ***2) Non-ferrous resources***, which include the Mesoproterozoic (1.1 Ga) Cu-Ni-Co-PGE and Ti-V deposits of the Mid-Continent Rift. Also, numerous mineral exploration programs in the Archean 2.7 Ga greenstone belts of Minnesota over the last 60 years have identified numerous prospective lode-gold and copper-zinc target areas. This written testimony includes as a supporting document a bedrock geology and mineral resource map of Minnesota that highlights the 8th Congressional District (Peterson, 2022).

Ferrous Resources

The ferrous mineral resources of Northern Minnesota include several categories of marine chemocline mineral systems outlined in recent USGS publications (Schulz et al., 2017 and Hofstra and Kreiner, 2020). These categories include: 1) Superior-type iron deposits (Mesabi Range), 2) Iron-Manganese deposits (Cuyuna Range, 100 million tons), and 3) Algoma-type iron deposits (Vermilion Range (102 million tons). Brief descriptions of the geology and mineral resources of the Mesabi and Cuyuna iron ranges is provided below.

Superior Type Iron Resources of the Mesabi Iron Range

Superior type iron formation resources of Minnesota are exemplified by the long-standing mining of iron resources of the Biwabik Iron Formation along the length of the Mesabi Iron Range. The Mesabi Iron Range is largely located in St. Louis and Itasca counties and has been the most important iron ore district in the United States since ~1900. The Mesabi Iron Range is 120 miles long, averages one to two miles wide, and is comprised of rocks of the Paleoproterozoic Animikie Group. The Animikie Group on the Mesabi Iron consists of three conformable major formations: Pokegama Formation at the base; Biwabik Iron Formation in the middle; and the overlying Virginia Formation. On the Mesabi Iron Range, these three formations display gentle dips to the southeast at an angle of 3-15 degrees.

Leached and iron enriched direct ores (or natural ores) were the first materials mined from strongly oxidized pockets along fault and fracture zones and the blanket oxidation at the surface in the iron formation (Marsden et al., 1968), with the first shipment beginning in 1892. Taconite, which is the material that is mined today using magnetic separation methods, constitutes most of the iron formation and pertains to the hard, non-oxidized portions of the iron-formation. Maps of currently active taconite mining operations and the historic natural ore mines on the Mesabi Iron Range are presented on inset maps 1, 2, and 3 on the provided bedrock geology and mineral resources map (Peterson, 2022). Compiled grade/tonnage ore reserve calculations for the active taconite operations on the Mesabi iron range are given in Table 1.

Mn-Fe Resources of the Cuyuna Iron Range

The Cuyuna Range is about 160 km west-southwest of Duluth in Aitkin, Cass, Crow Wing, and Morrison Counties, and is part of a Paleoproterozoic (1.9 – 1.8 Ga) geologic terrane which occupies much of east-central Minnesota. Since their discovery in 1904, it has been recognized that the iron-formations and associated ore deposits of the Cuyuna Range contained appreciable quantities of manganese which was extracted as ferromanganese ores from several mines on the North range from 1911 to 1984. The presence of this manganese resource sets the Cuyuna range apart from other iron-mining districts of the Lake Superior region.

The Cuyuna iron range is traditionally divided into three districts, the Emily district, the North range, and the South range. The Emily district extends from the Mississippi River northward through Crow Wing County and into southern Cass County. Although exploration drilling has been extensive in the Emily district, mining never commenced. The North range, located near the cities of Crosby and Ironton in Crow Wing County, was the principal site of mining activity (ceased in 1984) of the Cuyuna. The South range, where only a few mines were operated in the 1910s and 20s, comprises an area of northeast-trending, generally parallel belts of iron-formation extending from near Randall in Morrison County northeast for about 100 km. In addition to the three named districts, numerous linear magnetic anomalies occur east of the range proper, and may indicate other, but as yet poorly defined, beds of iron-formation.

Several attempts have been made over the last 70 years to estimate the size of the manganese resources of the Cuyuna iron range. For example, Lewis (1951) estimated that 455 million metric tons of manganiferous iron-formation containing from 2 to 10 percent manganese were available to open-pit mining to a depth of 45 meters. Dorr et al., (1973) used that estimate to establish that the Cuyuna range contains approximately 46 percent of known manganese resources in the United States. US Steel geologist Richard Strong (1959) estimated iron and manganese resources from several well-drilled deposits in the Emily District and Beltrame et al., (1981) estimated a minimum of 170 million metric tons of manganiferous rock with an average grade of 10.46 weight percent manganese. All of these historic grade/tonnage estimates should be considered with a certain amount of skepticism as they do not conform to current best practices of mineral resource estimation. A listing of the grade and tonnage from properties that Strong (1959) and Beltrami et al., (1981) estimated manganese resources is given in Table 2.

Non-ferrous Resources

The non-ferrous mineral resources of Northern Minnesota include several categories of mafic magmatic mineral systems outlined in recent U.S. Geological Survey publications (Schulz et al., 2017 and Hofstra and Kreiner, 2020). These categories include: 1) Contact-type Cu-Ni-Co-PGE sulfide deposits; 2) Conduit-type Ni-Cu-Co-PGE sulfide deposits: and 3) Iron-Titanium oxide (Fe-Ti-V-P) deposits. All of these non-ferrous mineral resources are related to the 1.1 Ga Mid-Continent Rift. A summation of published values of known in-situ contents of base metals (Cu-Ni-Co) and precious metals (Pt-Pd-Au-Ag) for the contact-type and conduit-type mineral resources of Northern Minnesota is given in Table 3.

Contact-type Cu-Ni-Co-PGE sulfide deposits

Contact-type Cu-Ni-PGE magmatic sulfide deposits (Zientek, 2012) of the midcontinent of North America are exemplified by the large, mainly disseminated sulfide deposits that occur along the basal contact of the Duluth Complex where magmas intruded and incorporated footwall Paleoproterozoic Animikie Group metasedimentary rocks and Archean granitoids. Major deposits include Birch Lake, Maturi, Mesaba, NorthMet, Serpentine, and Spruce Road. Disseminated and local massive sulfide mineralization of the Duluth Complex was historically estimated to contain about 4.4 billion metric tons of ore with average grades of 0.66% Cu and 0.2% Ni at a 0.5% Cu cut-off (Listerud and Meinike, 1977). Recent exploration and project development for many of these Duluth Complex contact-type deposits has led to upgraded mineral resource estimates for many of these deposits via the publication of numerous Ni 43-101 compliant mineral resource estimates. Combined together the upgraded estimate contains 9.57 billion metric tons with average grades of 0.406% Cu, 0.126% Ni, and 0.326 g/t Pt-Pd-Au.

Conduit-type Ni-Cu-Co-PGE sulfide deposits

Conduit-type Ni-Cu-PGE sulfide deposits are defined as magmatic sulfide mineralization restricted to small- to medium-sized mafic and/or ultramafic tube-like intrusions or dikes that served as pathways for flow-through of picritic and/or Mg-rich basaltic magmas (Schulz et al., 2014). These important sulfide deposits are unique in that they typically contain more metal and sulfur than could be derived from a magma volume equal to the limited volume of the small intrusions that host deposits. This implies that these deposits were products of a greater volume of magma than the current volume of the host intrusion. Thus, conduit-type sulfide deposits are the product of a large volume of magma that moved through open conduit systems, enriching an immiscible sulfide liquid with metals such as Ni, Cu, Co, and PGE. Rocks that make up host intrusions generally do not represent primary magmas, but are accumulations of olivine, pyroxene, and immiscible sulfide liquid.

The Tamarack deposit is the only documented conduit-type sulfide deposit in Northern Minnesota. The ultramafic Tamarack Intrusive, with a minimum intrusion age of 1105.6±1.2 Ma (Goldner, 2011), is made up of several distinct intrusive bodies, including an ovoid-shaped Bowl Intrusion of oxide gabbro and two sulfide mineralized intrusive dike-like peridotite bodies that give the complex a tadpole shape (Taranovic et al., 2015). Mineralization at Tamarack consists of disseminated to net textured to massive pyrrhotite, pentlandite, chalcopyrite, and minor cubanite.

Ti-Fe-V Resources of the Duluth Complex

Small titanium-iron±vanadium oxide-rich, plug-like, discordant intrusions along the southern basal section of the Duluth Complex are called Oxide-Ultramafic Intrusions, or OUIs. Rock types carrying the Ti-Fe±V oxide mineralization in OUIs include dunite, peridotite, and pyroxenite, typically with more than 10% semi-massive to massive oxide zones (Severson and Hauck, 1990). Deposits, including the major OUIs Longnose, TiTac, and Water Hen, can also carry minor Cu sulfide mineralization.

Identified resources of Minnesota's OUI associated Ti-Fe-V deposits include the: 1) Longnose deposit, with a NI 43-101 indicated resource of 58.1 million tons averaging 16.6% TiO_2 (inferred 65.3 million tons averaging 16.4% TiO_2) based on 27 drill holes and using a cut-off grade of 8% TiO_2; 2) Titac deposit, with a NI 43-101 inferred resource of 45.1 million tons averaging 14% TiO_2 based on 32 drill holes and using a cut-off grade of 8% TiO_2 ; and 3) Water Hen deposit, with a crudely estimated 62 million tons averaging 14% TiO_2 and significant graphite resources, based on 37 drill holes.

Summary

Ore deposits represent the preferential concentration of specific elements within the earth via the transfer of mass and energy over space and time. The bedrock geology within the state of Minnesota represents a mosaic of geological terranes that facilitated ore-forming processes unique to this region and underpins a remarkable endowment of mineral resource wealth within the United States. The geology and mineral deposits of the Lake Superior area in general, and Northern Minnesota in particular, are unique. No other area of the United States of America hosts such an array of Precambrian rocks and the world-class ore deposits that these rocks contain. As the fifth most valuable state with respect to mineral production (USGS, 2022), Minnesota stands alone in its potential to advance the domestic supply of many critical minerals into the United States economy and lead the way toward a brighter future.

References

Beltrame, R.J., Holtzman, R.C., and Wahl, T.E., 1981, Manganese resources of the Cuyuna range, east-central Minnesota: Minnesota Geological Survey Report of Investigations 24, 22 p.

Dorr, J.VN., II, Crittenden, M.D., Jr., and Worl, RG., 1973, Manganese, in Probst, D.A., and Pratt, W.P., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 385-399.

Goldner, B.D., 2011. Igneous petrology of the Ni–Cu–PGE mineralized Tamarack Intrusion, Aitkin and Carlton Counties. Unpublished M.S. thesis, Univ. Minn.-Duluth, Duluth, MN, pp. 155.

Hofstra, A.H., and Kreiner, D.C., Systems-Deposits-Commodities-Critical Minerals Table for the Earth Mapping Resource Initiative: U.S. Geological Survey Open-File Report 2020-1042, 24 p.

Lewis, W.E., 1951, Relationship of the Cuyuna manganiferous resources to others in the United States, in Geology of the Cuyuna range-Mining Geology Symposium, 3rd, Hibbing, Minnesota, Proceedings: Minneapolis, University of Minnesota, Center for Continuation Study, p. 30-43.

Listerud, W.H., Meineke, D.G., 1977. Mineral resources of a portion of the Duluth Complex and adjacent rocks in St. Louis and Lake Counties, northeastern Minnesota. Minn. Dept. Nat. Res. Div. Min. Rep. 93, pp. 74.

Marsden, R.W., Emanuelson, J.W., Owens, J.S., Walker, N.E., and Werner, R.F., 1968, The Mesabi Iron Range, Minnesota, in Ridge, J.D. (ed.), Ore Deposits of the United States, 1933-1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., The Grafton-Sales Volume, v. 1, p. 518-537.

Peterson, D.M., 2022, Precambrian bedrock geology and mineral resources map of Minnesota: Highlighting the 8th Congressional District of the U.S. House of Representatives, Big Rock Exploration map BRE-Map-2022-01

Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., 2017, Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, 797 p., https://doi.org/10.3133/pp1802.

Schulz, K.J., Woodruff, L.G., Nicholson, S.W., Seal, R.R., III, Piatak, N.M., Chandler, V.W., Mars, J.L., 2014, Occurrence model for magmatic sulfide-rich nickel-copper-(platinum-group-element) related to mafic and ultramafic dike-sill complexes. U.S. Geol. Surv. SIR 2010-5070-I, pp. 80.

Severson, M.J., Hauck, S.A., 1990. Geology, geochemistry, and stratigraphy of a portion of the Partridge River intrusion. Nat. Res. Resch. Inst. NRRI/TR-59/11, pp. 149.

Strong, R., 1959, Report on Geological Investigation of the Cuyuna District, Minnesota, 1949-1959, US Steel Internal Report, 318 pages.

Taranovic, V., Ripley, E.M., Li, C., Rossell, D., 2015. Petrogenesis of the NI-Cu-PGE sulfide-bearing Tamarack Intrusive Complex, Midcontinent Rift System, Minnesota. Lithos, 212-215, 16-31.

U.S. Geological Survey, 2022, Mineral commodity summaries 2022: U.S. Geological Survey, 202 p., https://doi.org/10.3133/mcs2022.

Zientek, M.L. 2012. Magmatic ore deposits in layered intrusions – Descriptive model for reef-type PGE and contact type Cu-Ni-PGE deposits. U.S. Geological Survey OFR 2012-1010, 48 pp.

Mine	~ Year	Category	Tonnes	*Fe %
Northshore	2019	Proven & Probable	829,096,800	24.3
United Taconite	2019	Proven & Probable	817,920,250	22.3
Hibbing Taconite	2019	Proven & Probable	123,856,495	19.7
Minorca	2018	Proven & Probable	101,000,000	23.5
Minntac	2019	Proven & Probable	420,644,700	?
Keetac	2019	Proven & Probable	373,906,400	?

** Reported as recoverable magnetic Fe %*

~ Data compiled from company annual reports

Total Tonnes: 2,666,424,645

Table 1. Recent grade-tonnage reserve estimates of the Mesabi Iron Range taconite mines.

Property	Area	Year	Tons	Mn %	Mn lbs
West Ruth Lake Deposit	Emily District	*1959	24,012,200	15.28	8,088,891,898
Lake Mary Deposit	Emily District	*1959	8,536,562	8.30	1,561,700,137
East Ruth Lake Deposit	Emily District	*1959	4,874,300	7.65	821,956,313
Emily-Shawnut Reserve	Emily District	~1981	833,709	10.56	194,006,830
Zeno Reserve	North Range	~1981	1,284,211	12.81	362,676,390
Pontiac Mine	North Range	~1981	883,351	16.81	327,418,704
Gloria Mine	North Range	~1981	559,711	12.59	155,354,314
Sagamore Mine	North Range	~1981	641,491	8.79	124,279,088
Huntington Mine	North Range	~1981	866,032	3.59	68,479,191
Omaha Mine	South Range	~1981	1,507,189	3.14	104,335,269
Clearwater Lake Reserve	South Range	~1981	581,549	3.61	46,234,409

** Estimate from Strong, 1959*

~ Estimte from Beltrame et al., 1981

Total Mn (lbs): 11,855,332,543

Table 2. Historic grade-tonnage estimates (non-NI 43-101 compliant) of manganese resource within the Cuyuna Iron Range. Table only lists those properties with estimated >500,000 tons of ore.

Metal Contents		Current Metal Prices		
Metal	lb/oz	Price	Unit	*Value
Copper	85,627,994,908	$3.88	pound	$332,236,700,000
Nickel	26,279,521,449	$10.83	pound	$284,607,000,000
Cobalt	2,107,878,394	$15.84	pound	$33,389,000,000
Platinum	26,331,801	$1,074	troy ounce	$28,280,000,000
Palladium	66,140,009	$1,430	troy ounce	$94,580,000,000
Gold	14,453,135	$1,988	troy ounce	$28,733,000,000
Silver	419,059,542	$25.01	troy ounce	$10,703,000,000
			TOTAL:	$812,528,700,000

* Value rounded to the nearest million dollar
Data from NI 43-101 & related documents
April 28, 2023 metal prices

Table 3. *In-Situ* value estimate of the known mineral deposits of the Mid-Continent Rift in the State of Minnesota.