Explore Minnesota: TITANIUM

Northeastern Minnesota has ilmenite-rich deposits associated with the gabbroic intrusive Duluth Complex (Figure 1). The Duluth Complex is perhaps best known for the deposits of copper-nickel (± platinum group elements) that were first recognized in the 1950s along its western margin, along the basal contact zones of gabbroic and anorthositic intrusives and older Precambrian rocks (Figure 2). Subsequent exploration mapping in the 1960s along this western margin revealed the presence of several younger ultramafic plugs that intruded into the much larger Duluth Complex units. These oxide-rich plugs are referred to as Oxide-bearing Ultramafic Intrusions (OUIs), with at least 13 OUI bodies outlined by limited drilling (Figure 2).

The oxide minerals within these OUI plugs are typically coarse-grained ilmenite (iron-titanium oxide) and titanium-bearing magnetite. Ilmenite is the most important ore of titanium, and exploration drilling programs that began in the 1970s have identified some of these OUIs as potential TiO_2 resources. Drilling to date is only sufficient to define TiO_2 resources for 3 of the bodies: Longnose (24 drillholes indicated 58 million tons averaging 16.6% TiO2); Titac (36 drill holes inferred 45.1 million tons averaging 15% TiO_2); and Water Hen (37 drill holes, with a non-NI 43-101 compliant estimate of 62 million tons averaging 14% TiO_2).

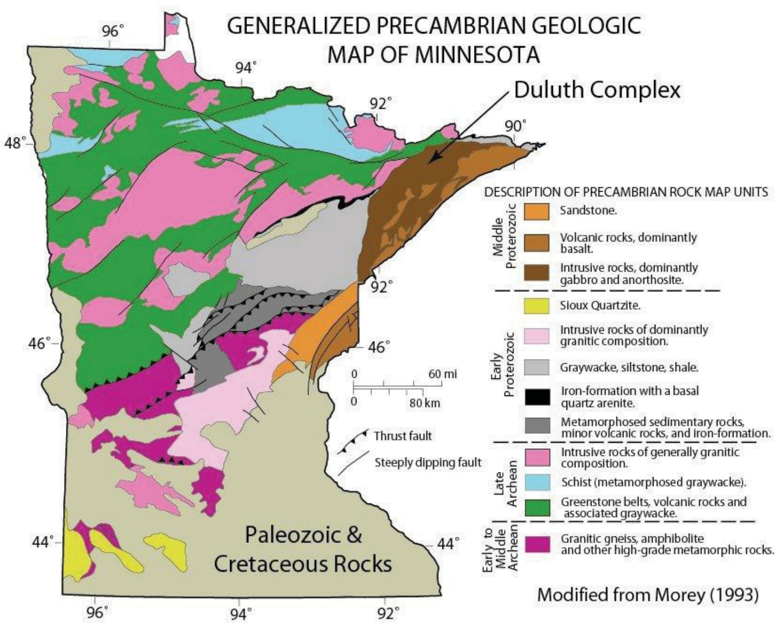

Figure 1 Generalized bedrock geology map of Minnesota

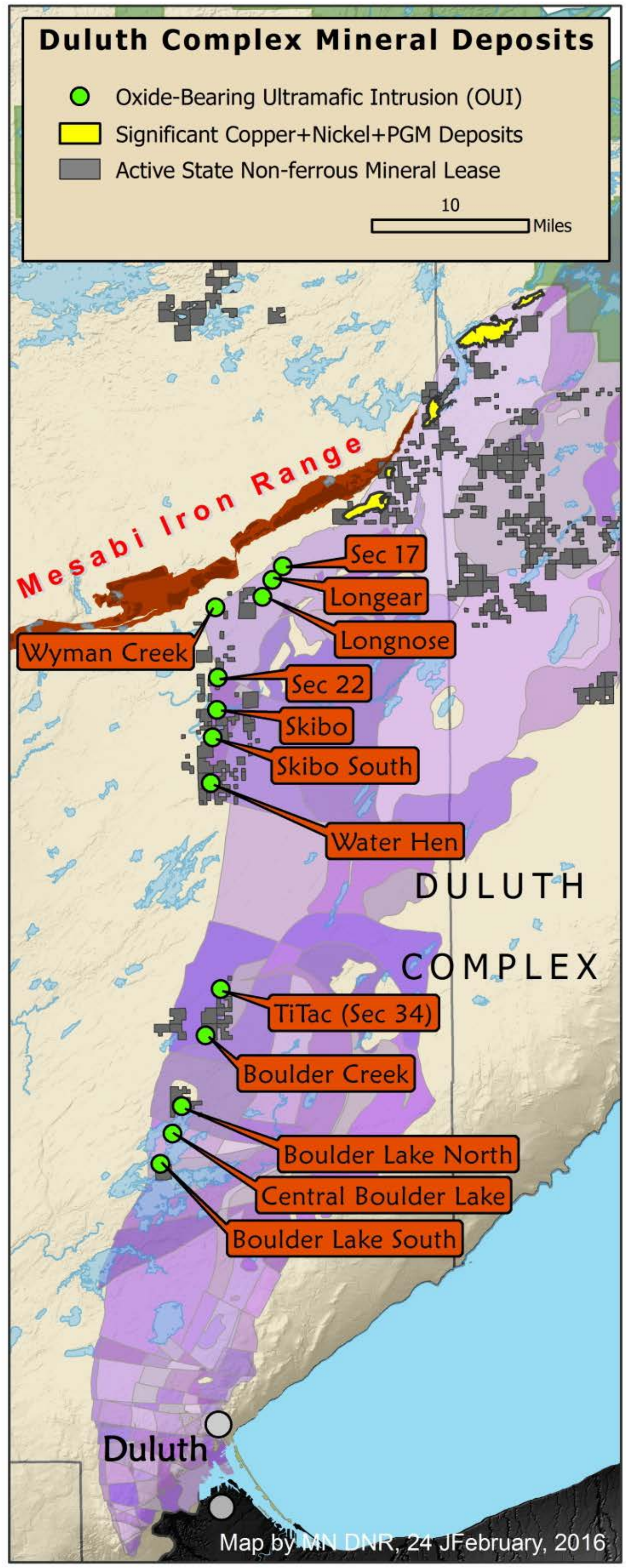

Figure 2: Location of OUIs and Cu-Ni-PGE deposits in Northeastern Minnesota's Duluth Complex

Deposit	Drill Holes	Avg. TiO_2 Wt. %	Max. TiO_2 Wt. %	Avg. V (ppm)	Max. V (ppm)	Resources in Mt
Longnose	27	12.49	30.37	1,325	4,400	58 Mt @ 16.6% TiO_2 (Indicated)
Water Hen	37	11.15	29.3	1,065	2,285	62 Mt @ 14% TiO_2 (not a NI 43-101 –compliant estimate)
Longear	3	18.06	50.5	580	3,590	?
Titac (Sec. 34)	32	15.66	26.74	2,610	4,035	45 Mt @ 15% TiO_2 (Inferred)
Sec. 17	6	33 analyses	14.66	790	950	?
Sec. 22	2	62 analyses	28.72	1,130	2,790	?
Skibo	9	18 analyses	25.28	165	220	?
Skibo South	1	3 analyses	12.6	1,100	1,346	?
Wyman Creek	4	10 analyses	28.65	?	540	?
Boulder Creek	2	8 analyses	19.09	4,630	8,125	?
Boulder Lake – North	3	6 analyses	35.2	4,045	6,835	?
Central Boulder Lake	1	no analyses	?	?	?	?
Boulder Lake – South	3	2 analyses	16.03	?	787	?

TiO2 and vanadium values in historic drill holes from the known OUIs. Note that most of the OUIs have been historically under sampled, and that in most of the table, the average TiO2 listings are not calculated for ore zones and include an unknown proportion of lean ore and waste rock.

Mineralogy

In some groups of OUIs, ilmenite is the dominant oxide, whereas titanomagnetite is dominant in others (Fig. 3). Oxide content in the OUIs ranges from 15% to 100% in localized massive oxide zones. Thick massive oxide zones are common to the Longnose deposit, which has been described by BHP as being "The largest, highest grade deposit of near-pure ilmenite in North America."

The OUIs are extremely low in deleterious co-products (U, Th, Zr, REEs) that are typically associated with currently-mined titanium placer deposits.

Copper-nickel minerals occur in varying amounts. At the Water Hen intrusion, it's 2-5 modal percent, with predominant pyrrhotite with minor cubanite, chalcopyrite and pentlandite. At the Titac prospect, the intrusion contains up to five modal percent copper minerals (predominately chalcopyrite and bornite). This is significant enough to be considered an additional resource; Cardero Resource Corp, in a 2011 press release, identified the Titac North and Titac South targets as Iron-Titanium-Copper Deposits, with mineralized drill core intercepts displaying copper concentrations of 0.2 – 0.5 wt %.

Almost all of the OUIs are close to the surface and would be amenable to open pit mining with minimal stripping of overburden.

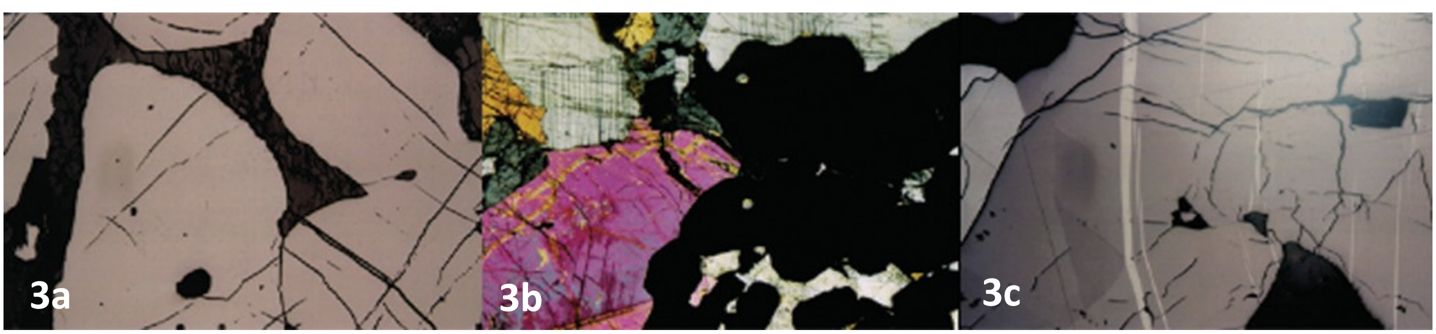

Figure 3: Photomicrographs of titanium ore:3a) subround ilmenite (reflected light); 3b) plagioclase, olivine and titanium oxides (polarized light); 3c) magnetite with ilmenite lamellae and ilmenite (reflected light). From NRRI (2010)

Resource Potential

Limited drilling to date has outlined at least 13 ilmenite-bearing OUI bodies along the western margin of the Duluth Complex (Figs. 2 & 5). Inferred and indicated resources have been been defined by a NI-43 101-compliant estimate at only two of these locations. The roots/feeder conduits of the various OUIs have never been drilled and may contain significant PGE credits. In addition, it may also be possible that weathering during the Cretaceous may have produced titanium beach sands along the eastern shoreline of an inland sea (the shoreline could be located just west of the present-day Duluth Complex basal contact). The presence of a thick saprolite cap over the Water Hen OUI (Fig. 6) suggests that such a mechanism could have occurred during the Cretaceous.

Processing

Significant amounts of historical beneficiation work has been conducted on OUI titanium deposits by the Coleraine Minerals Research Lab, which is part of the Natural Resources Research Institute. While this work pre-dates the establishment of NI 43-101 standards, two independent NI 43-101 technical reports stated that this research was completed to high standards and would be useful in designing future beneficiation work (see Henderson and Ripke (2011) and Farrow and Johnson (2012)).

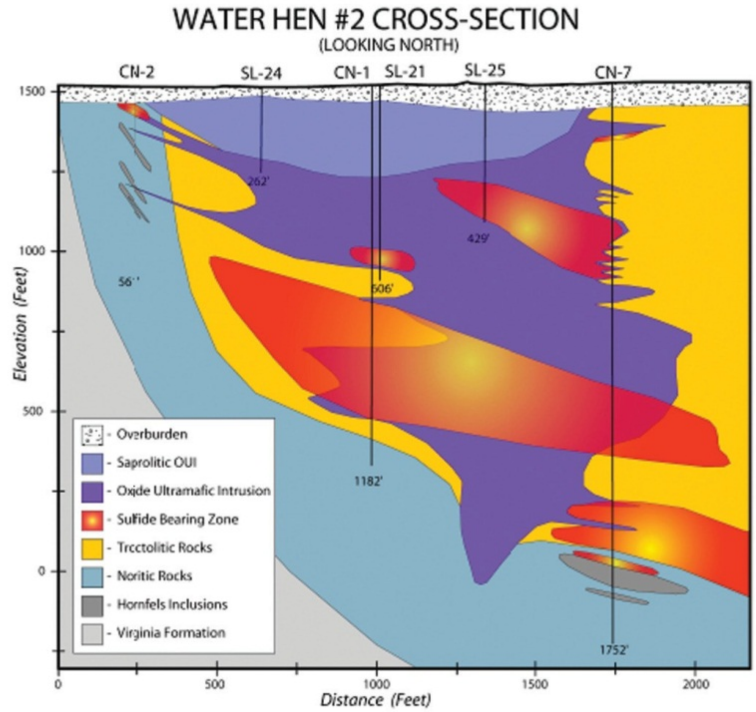

Figure 5: Cross-section of the Water Hen OUI body showing saprolite cap and sulfide-bearing zones within the OUI and adjacent gabbroic (troctolitic) rocks. Note that the root zone of the OUI has not been drilled. From NRRI (2010)

Pilot-scale Titanium Processing Project Secures $600k Funding in 2016

In February 2016, Minnesota's Iron Range Resources and Rehabilitation Board (IRRRB) approved a $300,000 grant (matched by the University of Minnesota) to the Natural Resources Research Institute (NRRI), to develop a pilot-scale titanium processing plant at the NRRI's Coleraine Minerals Lab.

The NRRI will work with Process Research Ortech to prove-out proprietary technology that produces a high-purity concentrate from titanium-bearing ore. The NRRI has already successfully processed more than 50 tons of material from the Longnose titanium deposit.

The IRRRB is a State of Minnesota development agency that provides grants to local government units, education institutions and non-profits to promote workforce development and sustainable communities. www.mn.gov/irrrb/

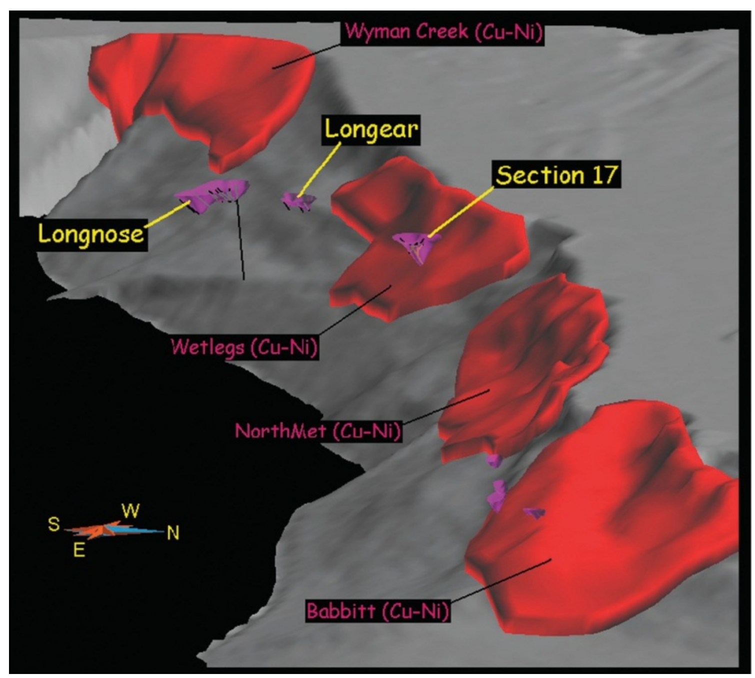

Figure 6: Spatial position of three OUI bodies (magenta) in relation to disseminated Cu-Ni deposits (red) at the basal contact (gray). From NRRI (2010)

Governance and Infrastructure: 100 Years of Support for Mining

Minnesota offers exploration companies a well-educated work force and a safe, conflict free work zone within a politically stable democracy. Its titanium prospects are located near the Canadian border, within a part of the State that has a 100-year tradition of large-scale iron mining. The public school system owns 3.5 million acres of mineral rights, from which it receives mineral royalties. State policy supports mineral diversification. There is a moderate overall taxation policy in comparison to Ontario. The State of Minnesota has also demonstrated willingness to support nonferrous mineral exploration and development by funding technological research by agencies and academic groups

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