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Unraveling the Genesis of Fe-Ti Oxide-bearing Ultramafic Intrusions in the Duluth Complex, Minnesota, USA

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The Duluth Complex is a 1.1 Ga large mafic intrusion that was emplaced as part of the Midcontinent Rift System. Located in northeastern Minnesota, the Duluth Complex hosts numerous types of mineral deposits, including Cu-Ni, PGE, Mn, Ti, and others, yet it remains largely undeveloped. Significant Fe-Ti ± V mineralization has remained particularly unstudied over the past 20 years and represents one of the United States' most promising domestic resources of these energy- and infrastructure-critical metals. Fe-Ti ± V mineralization is hosted in 14 oxide-bearing ultramafic intrusions along the western margin of the Duluth Complex. Although all are broadly similar in mineralogy, two contrasting genetic models have been proposed to explain the source of Fe and how the deposits formed. There exists incredibly scarce geochemical evidence to support or refute either of the models, and the main objective of this project is to unravel the genesis of Fe-Ti oxide-bearing ultramafic intrusions.

Focusing on the Longnose and Titac intrusions, two well-drilled intrusions ~40 km apart hosted in the Partridge River and Western Margin intrusions, respectively, we used detailed optical and microbeam methods to compare the textures and compositions of Fe-Ti oxides (ilmenite, titanomagnetite, and magnetite) and olivine to gain insight into their origins. Both intrusions show similar textures despite differing proportions of ilmenite and titanomagnetite, with Longnose having higher amounts of ilmenite. Olivine in both intrusions is serpentinized and fractured, and magnetite is present as thin, secondary veins that formed via serpentinization reactions, being more pervasive in the Titac Intrusion. Major and minor element compositions of titanomagnetite and ilmenite are similar between Longnose and Titac. Microtextural observations of ilmenite and titanomagnetite indicate complex temperature and redox trends during emplacement. Hematite lamellae in ilmenite, multiple types of pleonaste exsolution in titanomagnetite and ilmenite, and granule, sandwich, and trellis type ilmenite exsolution in titanomagnetite are found in both intrusions. These textures indicate that the original Fe-Ti oxide liquid underwent extensive subsolidus cooling and oxidation-reduction reactions starting at >900°C and was most likely assisted by deformation and secondary fluid incursions during and immediately following emplacement. Olivine from the Longnose Intrusion increases in forsterite content with depth (Fo_{60}–Fo_{68}), while olivine from the Titac Intrusion neither increases or decreases with depth and is typically ~Fo_{60}.

The initial results of this study point towards a similar complex, slow cooling history for Fe-Ti oxide liquids and a relatively primitive magma for both the Longnose and Titac intrusions, despite being emplaced in different rock types. Future work will involve measuring stable Fe and Ti isotopes of the ilmenite and titanomagnetite to fingerprint the metal sources and directly assess a key question in the genesis of the deposits.