Variation in the Cu-Ni-PGE Mineralization in the South Kawishiwi Intrusion, Duluth Complex, Northeastern Minnesota

Dean M. Peterson
Economic Geology Group, Natural Resources Research Institute, University of Minnesota, Duluth
email: dpeters1@nrri.umn.edu

Introduction

The Mesoproterozoic South Kawishiwi intrusion (SKI), which is exposed in a 32 x 8-kilometer arcuate band along the northwestern margin of the Duluth Complex, is composed dominantly of troctolitic cumulates. Footwall rocks to the intrusion include, from north to south, the Paleoproterozoic Virginia and Biwabik Iron Formations, and the Late Archean Giants Range batholith. Regional crosscutting features and remnant pillars and xenoliths indicate that the SKI intruded along the boundary between Mesoproterozoic volcanic and Anorthositic Series rocks and the older footwall strata. The SKI abuts the troctolitic Partridge River intrusion on the southwest, is inferred to be semi-conformable to the later Bald Eagle intrusion to the east, and abuts and cuts older Anorthositic Series rocks to the northeast. The basal mineralization within the SKI occurs dominantly in heterogeneous zones of troctolitic, gabbroic, noritic, and ultramafic rocks. This heterogeneity is a function of many factors, including footwall assimilation, dehydration and volatile fluxing from the footwall strata into the overlying magmas, chilling, and repeated magma injection. Multiple combinations of these phenomena in the basal portions of the SKI created footwall inclusions, zones of noritic rocks, and the distinctive heterogeneous troctolitic and gabbroic rocks that typify these contaminated zones. Ultramafic horizons probably represent inputs of more primitive magma.

Miller et al. (2002) subdivide the intrusion into five major map units from the base upwards: 1) a heterogeneous basal contact zone of sulfide-bearing troctolitic, gabbroic, and noritic rocks; 2) ophitic augite-troctolite; 3) poikilitic leucotroctolite; 4) ophitic troctolite; and 5) homogeneous troctolite. Severson (1994) and Zanko et al. (1994) have further subdivided the marginal zone of the intrusion into 17 different units, with sulfide mineralization dominantly confined to four units: the Basal Augite-Norite (BAN), Basal Heterogeneous (BH), Updip Wedge (UW), and Ultramafic 3 (U3) units. Minor mineralization higher up in the igneous stratigraphy of the intrusion occurs locally in the Ultramafic 1 (U1) and Ultramafic 2 (U2) units. Recent research has identified two dominant styles of mineralization ("Open" and "Confined") within the intrusion that have distinctive differences in their igneous stratigraphy, metal contents, timing, and mode of origin. Simplified regional geologic and mineralization style maps for the SKI are presented in Figure 1.

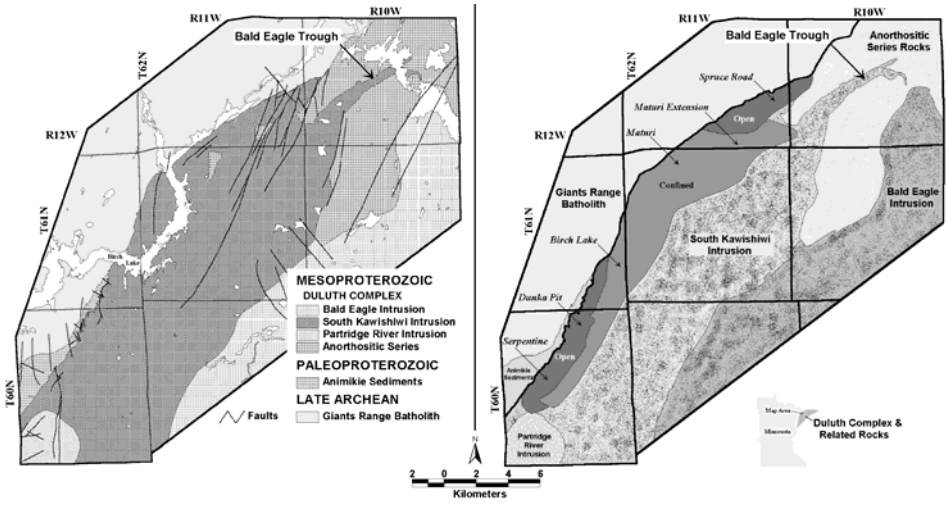

Figure 1. *Simplified regional geologic (left) and basal mineralization style (right) maps of the South Kawishiwi intrusion.*

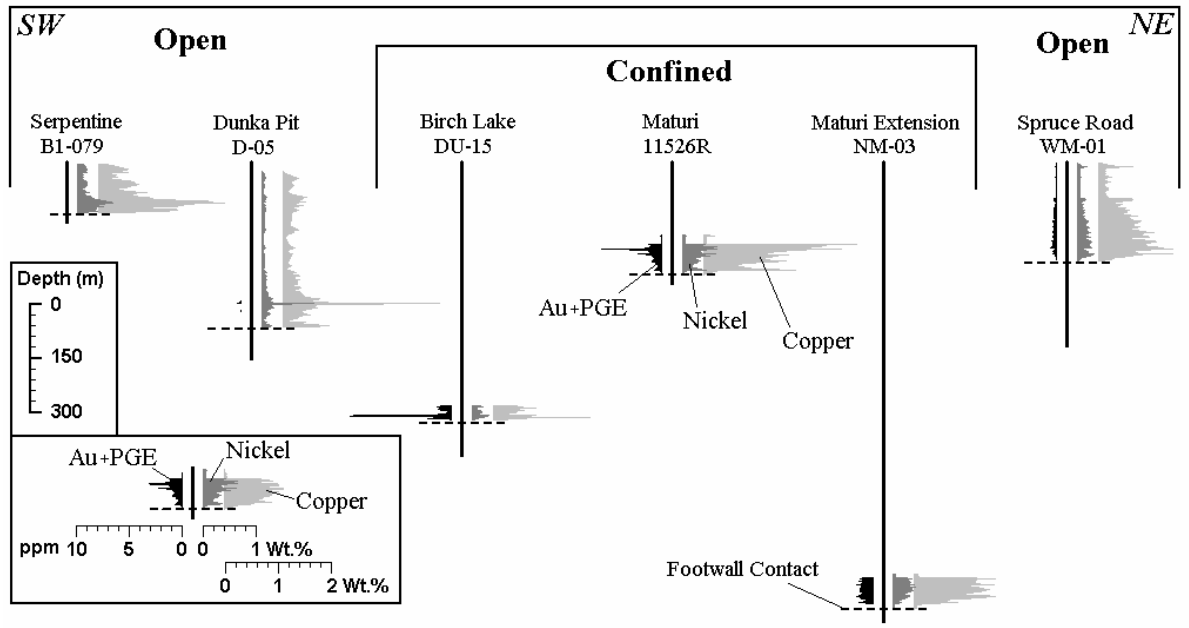

Figure 2. *Assay profiles from typical drill holes from each of the identified basal Cu-Ni deposits of the SKI.*

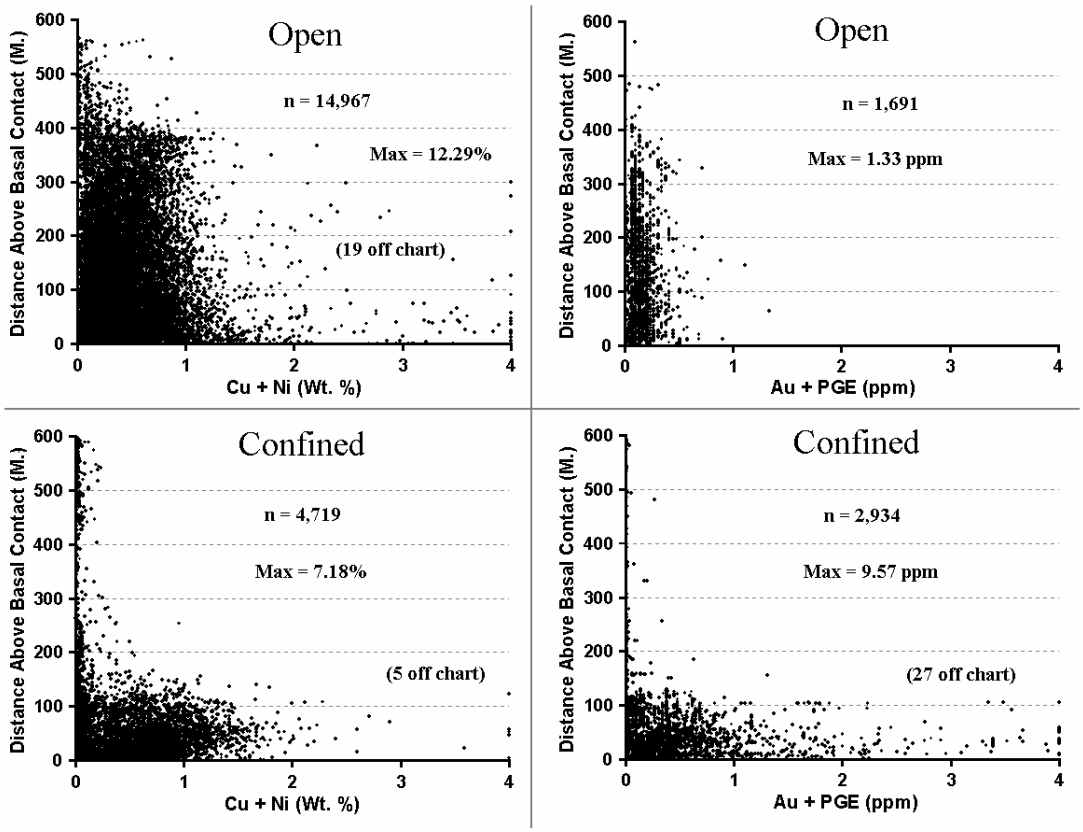

Figure 3. *Drill hole assay plots of Cu+Ni and Au+PGE versus distance above the basal contact for the Open and Confined styles of mineralization.*

Table 1. *Calculated cumulative Cu and Ni grade and tonnage inferred mineral resource estimates for the Open and Confined styles of basal mineralization of the South Kawishiwi intrusion. Open style modeled to 1500 Ft. (457m.) and Confined style modeled to 500 Ft. (152m.) above the basal contact.*

Open Style				Confined Style			
Copper Cutoff	**Cu %**	**Ni %**	**Tonnes**	**Copper Cutoff**	**Cu %**	**Ni %**	**Tonnes**
1.05	1.0429	0.5593	114,301	1.05	1.0354	0.2327	3,200,439
1.00	1.0287	0.4145	228,603	1.00	1.0098	0.2223	24,231,895
0.95	0.9690	0.3884	800,110	0.95	0.9891	0.2271	37,033,650
0.90	0.9329	0.3241	1,714,521	0.90	0.9624	0.2329	52,578,639
0.85	0.9244	0.3271	1,943,124	0.85	0.9358	0.2380	69,038,040
0.80	0.8442	0.3129	4,572,056	0.80	0.8925	0.2441	100,585,223
0.75	0.8183	0.3042	6,057,974	0.75	0.8519	0.2432	139,904,901
0.70	0.7575	0.2901	11,773,043	0.70	0.8016	0.2392	206,199,707
0.65	0.6854	0.2458	33,261,704	0.65	0.7482	0.2322	316,386,247
0.60	0.6443	0.2266	61,608,449	0.60	0.6925	0.2223	505,669,349
0.55	0.5969	0.2099	122,873,994	0.55	0.6409	0.2111	785,936,357
0.50	0.5466	0.1944	245,862,290	0.50	0.5895	0.1972	1,230,797,366
0.45	0.5021	0.1835	448,518,654	0.45	0.5528	0.1867	1,667,885,881
0.40	0.4607	0.1705	747,645,391	0.40	0.5168	0.1760	2,181,784,931
0.35	0.4211	0.1580	1,154,558,339	0.35	0.4821	0.1650	2,754,206,291
0.30	0.3740	0.1432	1,862,655,450	0.30	0.4462	0.1532	3,428,584,492
0.25	0.3294	0.1291	2,894,339,795	0.25	0.4081	0.1410	4,254,297,732
0.20	0.2857	0.1140	4,343,338,515	0.20	0.3690	0.1283	5,230,431,602
0.15	0.2421	0.0985	6,371,616,679	0.15	0.3285	0.1147	6,406,364,301
0.10	0.2008	0.0830	8,950,827,542	0.10	0.2828	0.0991	7,998,811,266
0.05	0.1563	0.0654	12,606,986,101	0.05	0.2187	0.0775	10,943,215,069
0.01	0.1070	0.0454	19,087,646,306	0.01	0.1308	0.0472	18,987,746,891

Note: 1) Cutoff grade intervals calculated from summation of modeled data (see Peterson, 2002). For example, the 0.55 Cu cutoff includes all gridded data that falls between 0.575 and 0.525 Wt.% Cu.. Cu %, Ni %, and Tonnes represent data from the Cu cutoff value and all data of higher grade. Low Cu cutoff data dominantly represents barren rock ***within*** *the mineralized zone of the Open style and barren rock* ***above*** *the mineralized zone within the Confined style.*

Several authors (Phinney, 1969; Weiblen and Morey, 1980; Chandler, 1990) have speculated upon a possible feeder zone for the Bald Eagle intrusion based on regional gravity data. This feeder zone may have also served as an earlier feeder for the South Kawishiwi intrusion (Peterson, 2001; Miller et al., 2002) in the area that separates the Bald Eagle and South Kawishiwi intrusions (termed here as the "Bald Eagle Trough").

Styles of Mineralization

Over the last fifty years, drilling for Cu-Ni resources in the SKI has defined numerous zones of disseminated Cu-Ni±PGE mineralization. The disseminated sulfides occur as interstitial grains that average about 1-5% (visual estimation) and range from trace amounts to 10%, with local zones of massive sulfide at the basal contact. Major sulfides are pyrrhotite, chalcopyrite, cubanite, and pentlandite. Pyrrhotite is generally the dominant sulfide, especially closer to the basal contact. Either chalcopyrite and/or cubanite are the dominant Cu-sulfide. Also present are minor amounts of bornite, talnakhite, chalcocite, digenite, mackinawite, valleriite, violarite, native copper, and platinum group minerals. Basal mineralization within the SKI has traditionally been divided into five distinct deposits: 1) Serpentine, 2) Dunka Pit, 3) Birch Lake, 4) Maturi, and 5) Spruce Road. Recent work by Wallbridge Mining Company and the author have defined a potential additional deposit area east of the Maturi deposit, informally named the Maturi Extension deposit. Although the style of mineralization in all of the deposits is dominated by disseminated Cu-Ni sulfides, differences occur between the deposits in igneous stratigraphy, Cu-Ni and PGE grade, mineralization thickness, and contained tonnes. Regional analysis of the drill hole assay data for all of the deposits of the South Kawishiwi intrusion has led to the identification of two main styles of mineralization associated with the base of the intrusion (Fig.1). These mineralization types include:

"Open" – vertically extensive (> 450 meters) mineralization with low - moderate Cu-Ni grade and low Au+PGE grades. Cu-Ni grades typically increase towards the basal contact although the mineralized zones are typically erratic in their spatial extent and grade and commonly interfinger in a random pattern with zones that are

barren of sulfides. Restricted zones of massive sulfide occur locally at the basal contact. This erratic pattern of mineralization, in part, mirrors the lithologic heterogeneity of the basal units. Examples of this open style include the Spruce Road, Serpentine, and Dunka Pit deposits.

"Confined" – vertically restricted (< 150 meters) mineralization with moderate - high Cu-Ni grades and moderate to very high (locally) Au+PGE grades. Cu-Ni grades typically are the highest near the top of the mineralized zone (units U3 and BH) and gradually decrease with depth toward the basal contact, and no zones of massive sulfide at the basal contact have been identified. For example, the upper portion of the mineralized zone within the Maturi deposit consistently exhibits copper values in excess of 1.0% that decrease to ~0.25% at the basal contact. Examples of the confined style include the Maturi, Maturi Extension, and the Birch Lake deposits.

Single drill hole assay profiles from each of the deposits are presented in Figure 2, and plots of base- and precious-metal assay values versus distance above the basal contact for the Open and Confined styles of mineralization are given in Figure 3. Regional geologic and crosscutting relationships (Fig. 1) indicate that the Open-style mineralization preceded the Confined-style. Moreover, the curvilinear nature of the contact between the styles of mineralization is similar to the regional contacts of most of the intrusions of the Duluth Complex (Miller et al., 2001 and 2002), and adds further support to this theory. Recently completed (Peterson, 2002) and ongoing research on the distribution of Cu and Ni within the South Kawishiwi and Partridge River intrusions is focused on generation a series of grade maps for each deposit areas. The maps depict modeled Cu and Ni grades in 50-foot (15.24-meter) levels above the basal contact. One outcome of this research is the calculation of new inferred mineral resource estimates of the grade and tonnage of Cu and Ni within the modeled areas (Table 1). The resource estimates further display the variation between the two styles of mineralization.

Conclusions

Basal Cu-Ni±PGE mineralization within the SKI can be divided into two dominant styles based on igneous stratigraphy, Cu-Ni and PGE grade, mineralization thickness, and regional location. The differences between the styles of mineralization reflect the different histories for the rocks hosting the mineralization. It is hypothesized that the early Open-style of mineralization reflects repeated small injections of sulfur-saturated, highly contaminated magma. In contrast, the Confined-style of mineralization reflects much larger batches of more primitive magma that may have incorporated much of its sulfur by assimilation of Open-style mineralized rocks (or remnant magma).

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