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# Bedrock Geology Map and Cu-Ni Mineralization Data for the Basal Contact of the Duluth Complex West of Birch Lake, St. Louis and Lake Countiues, Northeastern Minnesota

by

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## EXPLANATORY TEXT

This map is the outcome of eight days of field mapping by Dean M. Peterson in 2001 (Peterson, 2002e), and 6 days of mapping by the authors in 2002. The discovery of large (hundreds of meters long) gossanous expanses of Cu-Ni mineralized rock in the basal zone of the South Kawishiwi intrusion (SKI) in 2001 (in a historically under-mapped area) lead to the acquisition of funds to complete the subsequent detailed geological mapping that resulted in the publication of this map sheet. The mapping was completed at a scale of 1:3,000 and was concentrated within the Cu-Ni-PGE mineralized horizon immediately east of the basal contact of the Duluth Complex. Three mapping traverses were completed to the west into the footwall Neoarchean Giants Range batholith, and to the east into the unmineralized rocks of the SKI stratigraphically overlying the mineralized zone. The information generated from the detailed geological mapping was integrated with previous work by Phinney (1967), Miller et al. (2001), and Miller et al. (2002c), outside of the corridors of detailed mapping during the final compilation of this geologic map (see Fig. 1). In addition, geologic units intersected in the scattered drill holes in the area (see Severson, 1994) have been projected updip to the surface. The faults depicted on the map are interpreted from analysis of aeromagnetic data, steepening of the dip of the basal contact of the Duluth Complex (Figs. 2 and 3), and topographic lineaments. Digital data will be available online at http://www.nrri.umn.edu/egg/ in the fall of 2004.

## DESCRIPTION OF MAP UNITS

### MESOPROTEROZOIC (1.1 Ga.)

**Duluth Complex** - Multiphase intrusive igneous suite of the 1.1 Ga Midcontinent rift; generally subdivided into four major series that include the -early gabbroic, felsic, anorthositic, and layered- on the basis of lithology, internal structure, and intrusive relationships (Miller and others, 2002a). Rocks of the layered series (SKI) and the anorthositic series (isolated inclusions), as well as later rocks of unknown affiliation (oxide-ultramafic intrusions), are represented in this map sheet.

**Miscellaneous intrusive rocks** - Rock units that cannot be assigned to another series of the Duluth Complex.

Oui — ***Oxide ultramafic intrusion (Oui)*** - Coarse-grained to pegmatitic clinopyroxenite with 5 to 15 percent oxide content (ilmenite and titanomagnetite). Forms an interpreted NNW trending dike-like body cutting troctolitic cumulates in the center of the map sheet.

**South Kawishiwi intrusion** - East to southeast-dipping, layered mafic intrusion that forms the northwestern margin of the Duluth Complex. Predominantly composed of troctolitic (plagioclase-olivine) cumulates with local inclusions of anorthositic rock and volcanic hornfels. Extensive study of Cu-Ni-PGE exploration drill cores from the basal part of the intrusion indicates that it is divisible into multiple stratiform units traceable along strike (Severson, 1994; Miller and others, 2002b). The good exposure of the mineralized basal portion of the intrusion in this map sheet allows for the depiction of these stratiform basal units (the BAN, BH, U3, and PEG Units of Severson, 1994) onto this map sheet. Two significant Cu-Ni-PGE deposits have been identified to the south (Birch Lake) and northeast (Maturi) of this map, and the extension of the mineralization of both of these deposits is interpreted to occur within the map sheet (see Fig. 5).

Agt — ***Oxide olivine gabbro to augite troctolite cumulates (Agt)*** - Heterogeneous, coarse- to medium coarse-grained, subophitic to ophitic, poorly foliated; contains taxitic zones characterized by scattered augite-rich pegmatitic clots and patches; correlative with the Main AGT Unit of Severson (1994).

**Mineralized Basal Contact zone** - Vari-textured and taxitic olivine gabbro, troctolite, augite troctolite, olivine-rich troctolite, gabbronorite, and norite; commonly sulfide-bearing.

Peg — ***Pegmatitic Unit (Peg)*** - Medium to very coarse-grained, locally sulfide-bearing, troctolitic to gabbroic rocks that grade into pegmatoidal (1-2 cm) and pegmatite (>2 cm) zones. The unit occurs immediately above the U3 unit and separates the sulfide-bearing lower units from the sulfide-free upper units of the South Kawishiwi intrusion.

U3 — ***Ultramafic Three (U3)*** - Layered ultramafic (melatroctolite-peridotite) and troctolite horizons with lenses and pods of oxide-bearing (>5%) ultramafic rocks and/or massive oxide. The massive oxide horizons occur at the same stratigraphic level as the Biwabik Iron Formation (BIF) suggesting that assimilated BIF formed an oxide-rich "restite" within the intruding magma chamber (Severson, 1994). Disseminated sulfide occurs from trace amounts up to 5%, and typical include pyrrhotite, chalcopyrite, cubanite and pentlandite. The U3 is the dominant host rock for the PGE-rich mineralization in both the Birch Lake and Maturi deposits. Layered ultramafic U3 outcrops, as well as frost-shattered rubble occur in the northern and southern portions of the map sheet.

Bh — ***Basal Heterogeneous Zone (Bh)*** - The main sulfide-bearing unit in the map area that is characterized by vari-textured and taxitic troctolite, augite troctolite, anorthositic troctolite, and olivine gabbro with 0.5 - 5% disseminated pyrrhotite, chalcopyrite, cubanite and pentlandite. In the field area, the Bh unit occurs dominantly as a recessive weathered gossan (see top half of Fig. 2) of frost-shattered rubble immediately east of the basal contact of the Duluth Complex.

Ban — ***Bottom Augite Troctolite/Norite (Ban)*** - Vari-textured and taxitic, sulfide-bearing gabbronorite, norite, and augite troctolite. The unit grades upward into the Bh Unit - both are heterogeneous and are sulfide-bearing. In all likelihood the BAN Unit represents a footwall contamination zone of the Bh Unit along the basal contact (Severson, 1994). Outcrops of the Ban Unit occur in the southern portion of the map sheet, and generally are sulfide-poor (<2%).

**Anorthositic series** - Subsuite of the Duluth Complex composed predominantly of plagioclase cumulates displaying complex internal structure and lacking obvious signs of *in situ* differentiation. On this map sheet, all anorthositic series rocks occur as discrete inclusions within the Main Agt Unit of the SKI.

An — ***Anorthositic rocks undivided (An)*** - Mixed group of anorthositic cumulates occurring as inclusions within troctolitic cumulates of the SKI. Common rock types include troctolitic anorthosite, leucotroctolite, anorthosite, olivine anorthosite, and olivine gabbroic anorthosite. Olivine ranges from 2 to 15 percent in mode and from granular to poikilitic in texture, with oikocrysts ranging from 1 to 3 centimeters in diameter. Plagioclase mode ranges from 75 to 95 percent and varies from being nonfoliated to well foliated. Inclusions range in size from a few centimeters to elongate bodies hundreds of meters long that are parallel to foliation in the enclosing troctolite. Contacts with the enclosing troctolite, when found at outcrop scales, are generally sharp and highly irregular.

**North Shore Volcanic Group** - Tholeiitic plateau lava flows and minor interflow sedimentary rocks deposited during formation of the Midcontinent rift. In this map area, the rocks occur exclusively as isolated mafic hornfels inclusions of varied sizes in the lower units of the SKI.

Mv — ***Basaltic hornfels (Mv)*** - Fine-grained, granoblastic to poikiloblastic, massive to amygdaloidal basaltic hornfels.

### PALEOPROTEROZOIC (~1.9 Ga.)

**Animikie Group** - Supracrustal sequence of clastic and chemical sedimentary rocks deposited on the continental margin of the Superior craton in a foredeep basin during the later stages of the Penokean orogeny.

Bif — ***Biwabik Iron Formation (Bif)*** - Well-bedded, iron-bearing strata of alternating cherty and slaty intervals. The iron-formation exhibits strong recrystallization and partial melting where exposed in numerous test pits and dump piles immediately west of the basal contact of the Duluth Complex in the southern portion of the map sheet. The down-dip extent of this unit (see geologic map and Fig. 2) has been interpreted by the integration of derivative aeromagnetic anomaly maps and drill hole intersections.

### ARCHEAN (~2.68 Ga.)

**Giants Range batholith** - A multiply intruded complex of granitic rocks emplaced in supracrustal rocks of the Wawa subprovince of the Superior Province. Forms the footwall to the Biwabik Iron Formation and Duluth Complex in the map area.

Me — ***Equigranular Monzonite (Me)*** - Medium-grained granitic rocks of varied types including monzonite, monzodiorite, quartz monzodiorite, and diorite, occurring together with local biotite schist. Thin dikes and irregular bodies of aplite and granite are ubiquitous.

Mph — ***Porphyritic quartz monzonite (Mph)*** - Coarse-grained, hornblende-phyric, quartz-monzonite with large (1-2 cm) orthoclase phenocrysts. The unit locally contains irregular masses of biotite schist and is cut by thin dikes and irregular bodies of aplite, syenite, and granite.

## REFERENCES

Miller, J.D., Jr., Green, J.C., and Severson, M.J., 2002a, Terminology, nomenclature, and classification of Keweenawan igneous rocks of northeastern Minnesota, *in* Miller, J.D., Jr., Green, J.C., Severson, M.J., Chandler, V.W., Hauck, S.A., Peterson, D.M., and Wahl, T.E., Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, p. 5-20.

Miller, J.D., Jr., Green, J.C., Severson, M.J., Chandler, V.W., Hauck, S.A., Peterson, D.M., and Wahl, T.E., 2002b, Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, 207 p., 1 cd.

Miller, J.D., Green, J.C., Severson, M.J., Chandler, V.W., and Peterson, D.M., 2001, Geological map of the Duluth Complex and related rocks, Northeastern Minnesota; Minnesota Geological Survey, Miscellaneous Map M119, scale 1:200,000.

Miller, J.D., Severson, M.J., and Foose, M.P., 2002c, Bedrock geology of the Babbitt Northeast quadrangle, St. Louis and Lake counties, Minnesota: Minnesota Geological Survey Open File Report OFR 02-1, scale 1:24,000.

Peterson, D.M., 2001, Development of a conceptual model of Cu-Ni-PGE mineralization in a portion of the South Kawishiwi Intrusion, Duluth Complex, Minnesota: Laurentian University – Society of Economic Geologists, Second Annual PGE Workshop, Sudbury, Ontario, 3 p.

Peterson, D.M., 2002a, Copper-Nickel Grade Maps for the Spruce Road Deposit, South Kawishiwi intrusion, Duluth Complex: Natural Resources Research Institute, University of Minnesota, Duluth, Report of Investigations NRRI/RI-2002/03, 96 p.

Peterson, D.M., 2002b, Cu-Ni-PGE Mineralization in the South Kawishiwi Intrusion, Northeastern Minnesota; Variation due to Magmatic Processes: [abstract and oral presentation] Institute on Lake Superior Geology, 48th Annual Meeting, Thunder Bay, Ontario, v. 48.

Peterson, D.M., 2002c, 3-Dimensional View Through a Mineralized System: the South Kawishiwi Intrusion, Duluth Complex: [abstract and poster presentation] Institute on Lake Superior Geology, 48th Annual Meeting, Thunder Bay, Ontario, v. 48.

Peterson, D.M., 2002d, Shaded relief map of the basal contact of the South Kawishiwi intrusion, Duluth Complex, northeastern, Minnesota: Natural Resources Research Institute, Map Series NRRI/MAP-2002-01.

Peterson, D.M., 2002e, Bedrock geology, sample location, and property position maps of the west Birch Lake area, South Kawishiwi intrusion, Duluth Complex, northeastern, Minnesota: Natural Resources Research Institute, Map Series NRRI/MAP-2002-02.

Phinney, W.C., 1967, Reconnaissance geologic map of part of the Kangas Bay quadrangle: Minnesota Geological Survey, Open file map, scale 1:24,000.

Severson, M.J., 1994, Igneous stratigraphy of the South Kawishiwi intrusion, Duluth Complex, northeastern Minnesota: Natural Resources Research Institute, Technical Report NRRI/TR-3/34, 210 p., 15 pls.

Zanko, L.M., Severson, M.J., and Ripley, E.M., 1994, Geology and mineralization of the Serpentine copper-nickel deposit, Duluth Complex, Minnesota. Natural Resources Research Institute, University of Minnesota, Duluth, Technical Report, NRRI/GMIN-TR-93-52, 90 p.

## MAP SYMBOLS

- Duluth Complex basal contact; approximate, inferred
- Lithologic contact; approximate, inferred
- Fault; approximate, inferred
- Outcrop (darkened color)
- Inferred extent of preserved Biwabik Iron Formation beneath the Duluth Complex
- BL-90-3 — Drill hole location and the trace of the vertical projection of the hole
- 60 — Igneous modal layering
- 6 — Igneous lamination
- Gravel road
- Logging road, ATV trail

SCALE 1:10,000

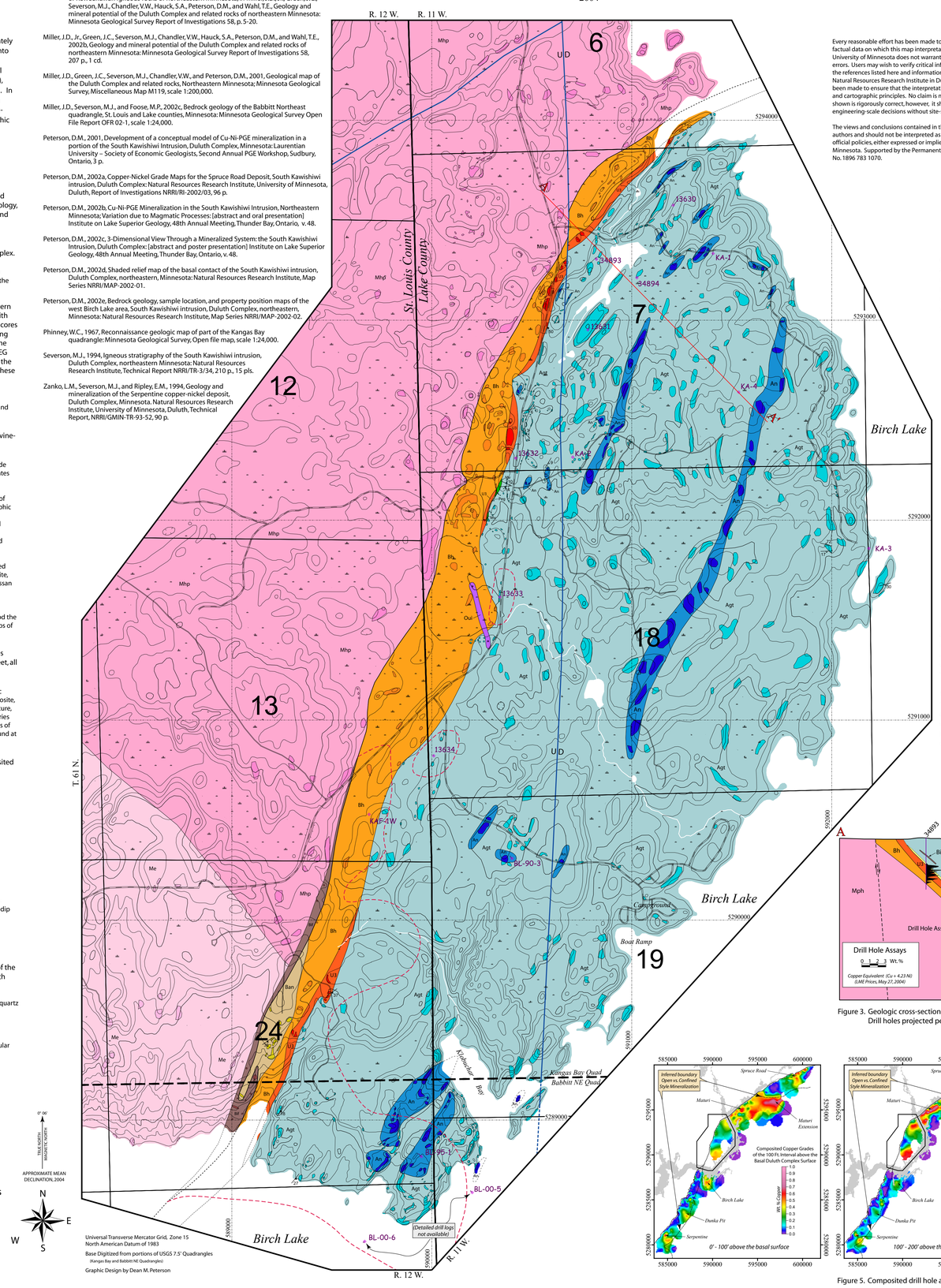
500 0 500 1000 Meters

1000 0 1000 2000 3000 4000 Feet

CONTOUR INTERVAL 10 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929






Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the University of Minnesota does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Natural Resources Research Institute in Duluth. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, it should not be used to guide engineering-scale decisions without site-specific verification.

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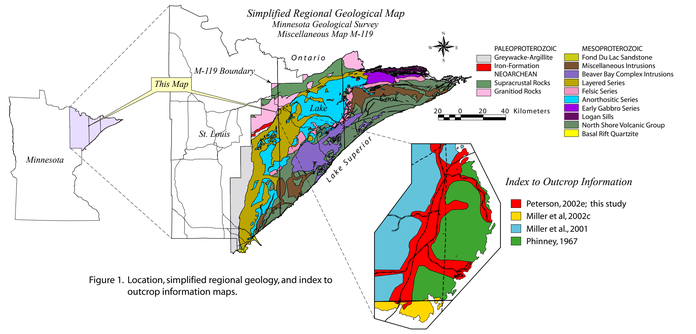


Figure 1. Location, simplified regional geology, and index to outcrop information maps.

## MINERALIZATION STUDIES

Over the last ~50 years, six Cu-Ni-PGE deposits have been discovered by mapping and/or drilling within the basal zone of the SKI. These deposits include, from south to north, the Serpentine, Dunka Pit, Birch Lake, Maturi, Maturi Extension, and Spruce Road deposits. Recent analysis by Peterson (2001, 2002a-d) of assay data from all of the holes drilled in the SKI lead to the identification of two main styles of mineralization associated with the base of the intrusion. These mineralization types include:

**1) "Open"** - vertically extensive (> 450 meters) mineralization with low - high 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, and/or immediately below, the basal contact. The erratic pattern of mineralization in part mirrors the lithologic heterogeneity of the basal units and may reflect repeated input of small pulses of barren and sulfur-contaminated magma. Examples of this "Open" style include the Spruce Road, Serpentine, and Dunka Pit deposits. The Serpentine deposit is unique within this group as it contains significant tonnage of massive sulfide at the basal contact that are associated with an immediate footwall sulfide source (Zanko et al., 1994).

**2) "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 only limited zones of massive sulfide occurring at, and/or immediately below, 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. The spatial continuity of both the igneous stratigraphy and, to a lesser extent, the Cu-Ni-PGE grades of this style of mineralization point toward larger sustained inputs of magma (and/or more turbulent input of magma, thus higher fractionation of base-and precious-metals into the sulfide fraction) than the "Open" style. Examples of the "Confined" style include the Maturi, Maturi Extension, and the Birch Lake deposits.

Drill hole assay plots of Cu + Ni and Au + PGE for both the open and confined styles of mineralization within the SKI are presented in Figure 4. Copper grades for 100 ft. intervals up to 500 ft. above the basal surface of the SKI are presented in Figure 5. In addition, Figure 5 gives the location of the identified Cu-Ni-PGE deposits associated with basal mineralization and the interpreted boundaries between the "Open" and "Confined" styles of mineralization.

The basal mineralization of the SKI within this map sheet is located within the "Confined" area as defined by Peterson (2001, 2002a-d). Visual analysis of the copper grade maps given in Figure 5 indicate that the mineralization in the northern portion of the map is the extension of the Maturi deposit to the west of Birch Lake, and the mineralization to the south may be the northern extension of the PGE-rich Birch Lake deposit.

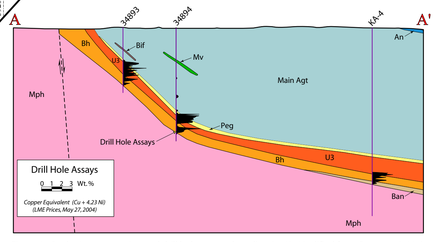


Figure 3. Geologic cross-section and drill hole assays along line A - A`. Modified from Severson (1994). Drill holes projected perpendicular to the line of section, no vertical exaggeration.

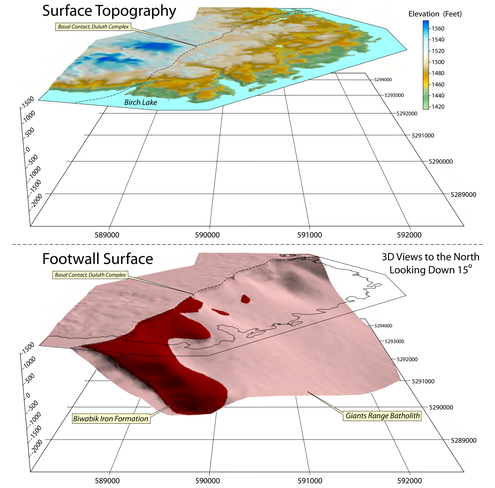


Figure 2. Three-dimensional topographic and Duluth Complex footwall surface maps. Footwall surface modified from Peterson (2002d).

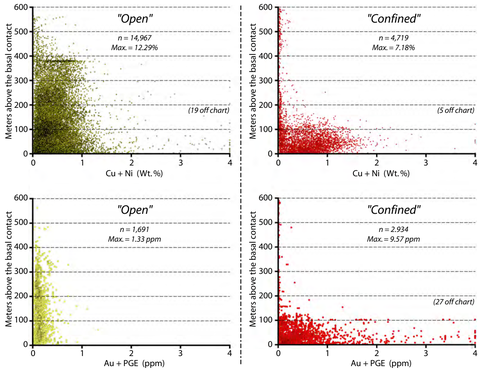


Figure 4. Drill hole assay plots of (Cu + Ni) and (Au + PGE) for the "Open" and "Confined" styles of mineralization. Data from Peterson (2002a).

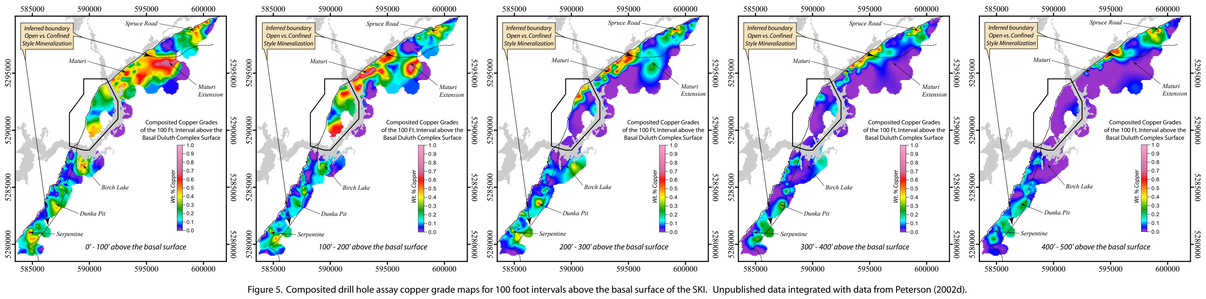


Figure 5. Composited drill hole assay copper grade maps for 100 foot intervals above the basal surface of the SKI. Unpublished data integrated with data from Peterson (2002d).