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A petrological model for emplacement of the ultramafic Ni-Cu-PGE Alpha complex, Eastern Interior, Alaska

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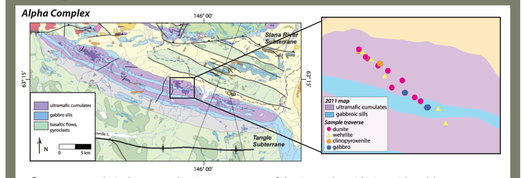
Objectives

The Alpha complex is a mineralized Ni-Cu-PGE mafic-ultramafic intrusive complex located within the Wrangellia Terrane in the Eureka Creek area of the Eastern Alaska Range. The complex has been variably interpreted as a layered mafic intrusion, a differentiated mafic-ultramafic complex, and as a multiphase complex of sills and possibly ultramafic extrusive rocks. Previous industry-led exploration has yet to converge on a geological model for the complex that adequately explains multiple aspects of the observed mineralization and crystallization patterns. Due to poor exposure and a lack of chilled margins, it is not immediately clear whether this is a single body or a multi-sill complex.

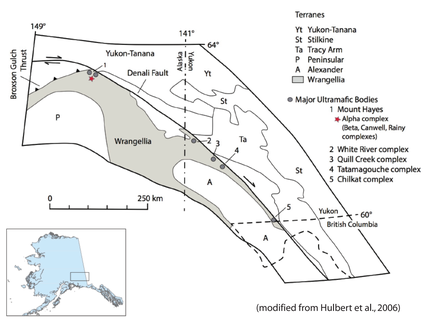
The purpose of this research is to approach the problem from a systematic perspective looking at compositional changes observed in the mineralogy of the complex across a detailed transect in order to better map and understand the petrological subdivisions of the complex, and to assess the degree of sulfur saturation and mineralization potential for each. The final product will identify the most suitable geological model, which is critical to the exploration strategy and could potentially lead to discoveries of more highly mineralized zones in the complex.

Background



- 1:50,000 scale industry geologic map, inaccurate at high scale (adapted from Hulbert et al., 2011)
- 30-km long, 3-km wide sill-form body consists of cyclically alternating layers of dunite and peridotite with gabbro
- Southward dipping lithology forms a syncline with the Beta complex to the south
- Intrusion is thought to have been a feeder system to the overlying Nikolai Basalt

Tectonic Setting



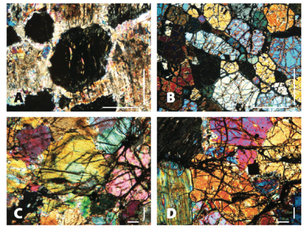
(modified from Hulbert et al., 2006)

- Simplified map illustrating the tectonic framework of northern Wrangellia and the lateral confines of Triassic ultramafic-mafic bodies extending from northern British Columbia (Chilkat complex) to east-central Alaska (Mount Hayes)
- The Alpha complex is located along the north eastern margin of the Wrangellia Terrane, along strike to the belt of Triassic aged, lithologically zoned mafic-ultramafic intrusions known in the Yukon as the "Kluane Mafic-Ultramafic Belt"

Wrangellia:

- Wrangellia is one of the largest accreted terranes of western North America and can be traced discontinuously from southern Alaska to as far south as eastern Oregon over a distance of 2000 km (Hulbert et al., 2006)
- Paleomagnetic evidence suggests that the Triassic basalts were extruded at low latitude (<20°) in the Pacific Ocean such that Wrangellia was situated near the paleoequator in the Triassic (Schmidt et al., 2007)
- Wrangellia subsequently migrated northward and was accreted on to the continental margin in the mid-Cretaceous or Jurassic
- The Mt. Hayes quadrangle, in which the Alpha complex resides, is proposed to represent the main center of the Wrangellia Triassic magmatic system in Alaska

Lithologies



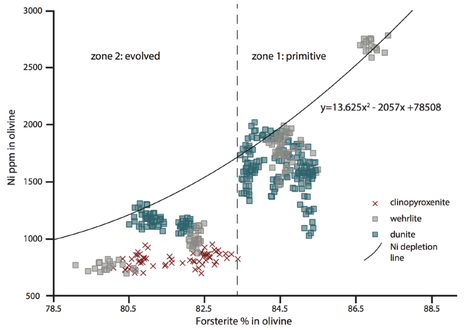
Dunite: Olivine is medium to coarse grained, euhedral, and granular (B). Minor clinopyroxene is subhedral to anhedral and poikiolitic in the majority of samples, with inclusions of olivine. It also exhibits abundant exsolution and in some samples is partially altered to amphibole (C). Chromite occurs as disseminated octahedral grains, both as inclusions within olivine and interstitial between silicate grains. Olivine exhibits variable amounts of serpentinization.

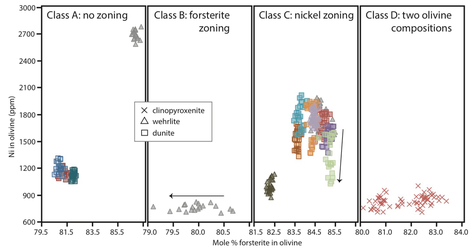
Wehrlite: The modal proportion of olivine in wehrlite varies from 40-75%. Grains of olivine and clinopyroxene are tightly packed and have an adcumulate texture, with little to no interstitial material. Clinopyroxene is commonly poikiolitic with inclusions of olivine and minor fine-grained chromite. Olivine exhibits pervasive alteration to serpentine and is altered to a mix of serpentine and Fe-oxide in the most highly serpentinized samples (A). Serpentine and magnetite veinlets are common along olivine grain boundaries in more highly altered samples.

Clinopyroxenite: Clinopyroxenites are composed on average of 93% clinopyroxene, with less than 7% of olivine, amphibole, oxides, and sulfides. Clinopyroxene varies from medium to coarse grained, granular, and often exhibits abundant exsolution lamellae (D). Minor amphibole forms coarse, subhedral grains, though both amphibole and pyroxene are colorless so they are difficult to tell apart. Some of the amphibole appears to be an alteration product of clinopyroxene.

Ni Depletion in Olivine

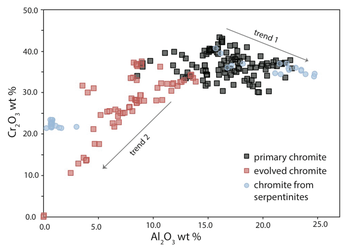
- The sample transect can be split spatially into a primitive, Mg-rich zone of olivine grains (zone 1: Fo83-88) and a more evolved zone of Mg-depleted olivine (zone 2: Fo80-83)
- The forsterite component of olivine shows no correlation with modal mineralogical patterns and none of the rock types show systematic variations with the degree of evolution of the magma
- Each sample can display a broad range in the level of Ni depletion, which has implications for when sulfide saturation was reached and for alteration of the olivine following crystallization





- Nickel in olivine shows a systematic positive correlation with the forsterite content, though several different patterns of zoning can be observed within samples
- The first class (type A) of olivine has grains exhibiting no significant zoning in either forsterite content or Ni concentration
- The second class of samples (type B) contains olivine grains that exhibit normal core to rim forsterite zoning, which would be expected for routine fractional crystallization
  - As a given magma evolves, the Fe/(Fe+Mg) ratio in olivine should increase due to fractional crystallization, as Mg is removed from the magma
- The third class of grains (type C) exhibit little to no zoning with respect to major elements (Mg and Fe) but have considerable zoning with regards to nickel
  - The nickel depletion observed in the core to rim transition may record a sulfur saturation event that took place while the olivine was still crystallizing
- The fourth class (type D) is only comprised of one sample but it exhibits olivine grains with two distinct compositions
  - The subset of low forsterite olivine likely experienced re-equilibration with surrounding intercumulate silicate melt subsequent to crystallization

Chrome Spinel Compositional Variations

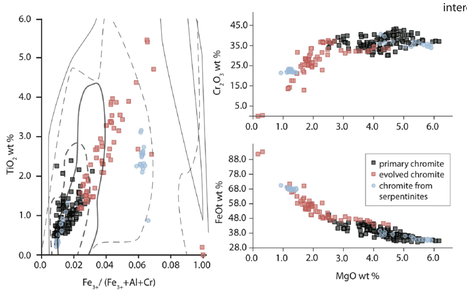


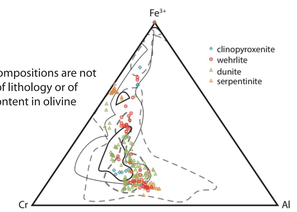
Cr-Al trend:

- Cr2O3 and Al2O3 exist in the same site in chromite, so in primitive, Mg-rich, Fe-poor silicate magma, they will show a negative correlation
- As chromite crystallized from a more evolved, Mg-depleted and Fe-enriched silicate magma, more Fe3+ would enter the site and cause Cr and Al to decrease at the same rate
- Thus, primary magmatic chromite demonstrate a negative Cr-Al correlation (trend 1) and more evolved chromite exhibits a positive Cr-Al correlation (trend 2)

Other elemental relationships:

- Evolved magmatic chromites in the complex exhibit a positive correlation between the MgO and Cr2O3 contents
- The decrease of MgO was caused by the re-equilibration between the chromite and coexisting silicates (primarily olivine) with falling temperature
- During evolution of the magma the Fe/Mg ratios and TiO2 contents increase in the melt, resulting in their positive correlation
- Trend may be accentuated by ongoing reaction of spinels with evolving trapped intercumulus magmas (Barnes and Roeder, 2001)

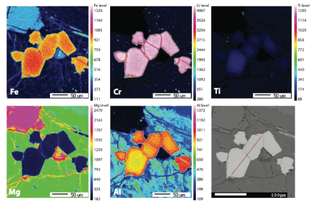




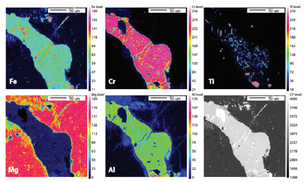
Chromite compositions are not a function of lithology or of forsterite content in olivine

Lines are data density plots from Barnes and Roeder, 2001

Dashed lines are for chromite from layered mafic intrusions and solid lines are for chromite from intrusions in flood basalt provinces



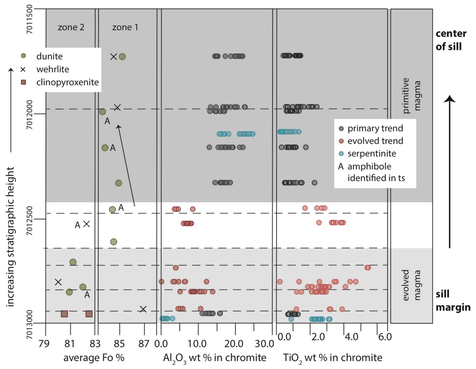
Elemental maps for Fe, Cr, Ti, Mg, and Al and the corresponding BSE images for three zoned, euhedral chromite grains from a dunite sample (above) and chromite with oxidative exsolution of ilmenite along the {111} plane and thin magnetite veinlets (below).



Euhedral chromite: Most chromite grains are interstitial to silicate minerals and occur as euhedral to subhedral grains from 20 to 200 microns across. These grains show no exsolution or alteration to magnetite but exhibit variable amounts of compositional zoning. Cores are Fe- and Ti-rich and Al-poor. Rims are slightly depleted in Cr and enriched in Al due to removal of Cr from the melt during crystallization.

Oxidative exsolution of ilmenite: Less commonly, chromite grains exhibit oxidative exsolution of ilmenite. Ilmenite can be observed exsolving along the {111} planes of the chromite (left) and as irregular blebs that have exsolved along chromite grain boundaries. The ilmenite lamellae occur as elongate crystals, generally 5 to 20 microns in length and <5 microns in width. The irregular blebs of ilmenite almost always occur along chromite grain boundaries, rarely within grains. They are generally elongate, although some have formed larger, anhedral crystals.

Implications



- The change in the MgO/FeO ratio of the parental magma is coupled by a distinct change in Al2O3 contents in chromite
- The bottom of the traverse has the most evolved forsterite compositions; moving towards the top of the traverse, olivine compositions on average become increasingly primitive
  - The dashed lines represent potential modal layers within the sill and were determined from the Fo content of olivine so that within a single layer olivine is becoming more evolved
- The two zones were crystallized from what was most likely a single magma progressively evolving during crystallization so that the hottest portion of the intrusion crystallized dunite and the margins crystallized more pyroxene-rich wehrlite and clinopyroxenite
- This traverse represents half of one sill that crystallized inward so that the perimeter is the most evolved and the center has the most forsterite rich, primitive olivine compositions

Conclusion

- Olivine and chromite compositions from the section of the complex that I have analyzed so far indicate that this section is a single intrusion that experienced in situ crystallization. This resulted in more evolved olivine compositions at the base of the traverse and more primitive olivine compositions towards the end of the traverse, near the center of the sill.
- Dunite and wehrlite form the core and more pyroxene-rich rocks crystallized near the edges of the intrusion. However, the crystallization evolution of the sill is not apparent in large scale lithological changes, it only becomes apparent when looking at discrete patterns in mineral chemistry.
- There are no obvious patterns between the silicate mineralogy and the degree to which layers in the intrusion were depleted in Ni. This indicates the entire sill may have become sulfur saturated early on, and remained saturated until it was fully crystallized.
- Future work will involve more detailed mapping of the area and increasing the sample set to cover a larger portion of the complex. This will aid in better characterization of different sills within the complex and will allow us to more conclusively propose a model of emplacement and mineralization for the complex.

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Acknowledgements

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