

**DISTRIBUTION, OCCURRENCE, AND CRYSTALLIZATION OF CHROMITE AND OLIVINE IN THE LOWERMOST PERIDOTITE ZONE, STILLWATER COMPLEX, MONTANA; Roger W. Cooper, Department of Geology, Lamar University, Beaumont, TX 77710**

Distributional relationships of chromite and olivine were characterized, in detail, to identify and evaluate nucleation and crystallization processes in ultramafic cyclic units under equilibrium to near-equilibrium conditions in an ultramafic to mafic layered intrusion. The data, outlined below, suggest that homogeneous saturation of chromite and possibly olivine was the dominant nucleation process. Further, chromitites and enclosing cyclic units appear to be the result of a balance among: (a) the degree of magma crystallization, (b) the extent of substrate cooling, (c) the latent heat of crystallization, (d) the amount of rejected solute, (e) compositional modification and gradients, (f) the time interval between successive magma pulses, and possibly (g) hydrostatic pressure variation during and following magma influx.

The data do not suggest or indicate that heterogeneous nucleation as proposed by (1) was an important process. In addition two-phase convection (2) was not a major process in the crystallization of ultramafic cumulates and cyclic units in the Stillwater Complex. The data also indicate that chromitites are not the result of magma mixing of similar or dissimilar magmas as suggested by (3) and (4).

The Chrome Lake area represents the easternmost occurrence of the Basal series and lowermost Peridotite zone in the Stillwater Complex. Two stratigraphic sections in the area with a horizontal separation of 155 meters were investigated in detail. The uppermost Basal series consists of medium-grained (1-2 mm) equigranular orthopyroxene mesocumulates averaging 75% cumulus orthopyroxene with isolated traces of cumulus chromite. Intercumulus phases include an average of 14% plagioclase, 10% oikocrystic clinopyroxene, 0.7% sulfide and traces of amphibole and phlogopite. The overlying Peridotite zone is composed of a sequence of olivine-chromite mesocumulates (chromite-bearing harzburgites) and local chromitites. The medium-grained (<1-2 mm) olivine-chromite cumulates consist of 50-90% cumulus olivine and 1-5% cumulus chromite. Intercumulus or interstitial phases include 5-50% orthopyroxene, 3-15% plagioclase, 0-2% clinopyroxene, and traces of amphibole, phlogopite, and sulfide. Chromite cumulates are composed of 68-90% chromite, 6-16% plagioclase, 4-8% orthopyroxene, and minor amounts of clinopyroxene, olivine, amphibole, phlogopite, and sulfide.

All identifiable chromite crystals in 27 thin sections of olivine-chromite cumulate were characterized according to crystal size, setting, distribution, enclosing silicate phases, and proximity to other chromite crystals. Of the 15 crystal settings that were identified, 6 settings account for over 99% of the occurrences. These include chromite: (a) totally enclosed in cumulus olivine, (b) totally enclosed in interstitial orthopyroxene, (c) totally enclosed in interstitial plagioclase, (d) along an olivine-orthopyroxene crystal contact, (e) along an olivine-plagioclase crystal contact, and (f) along an olivine-olivine crystal contact. In general 50% of all chromite crystals are totally enclosed in olivine, approximately 15% are totally enclosed in orthopyroxene and/or plagioclase, and 35% occur along silicate crystal contacts. The percentage of chromite crystals enclosed in olivine decreases slightly in olivine-chromite cumulates immediately adjacent to chromitite seams while the percentage enclosed in intercumulus orthopyroxene and plagioclase increases.

Within olivine-chromite cumulates, 70-80% of all chromite crystals occur as single crystals (i.e. they are not in physical contact with another chromite crystal) and 10-15% are in physical contact with only one other chromite crystal. Less than 15% of all chromite crystals form, are part of, a chain or cluster of 3 or more crystals. This suggests that homogeneous saturation and nucleation was the major chromite crystallization process as opposed to heterogeneous nucleation and growth.

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Three magma pulses/influxes were identified within the olivine-chromite cumulate sequence based on chromite crystal abundance (expressed as chromite crystals per unit area because all identifiable chromite crystals in an individual thin section were counted). The first two magma pulses generated enclosed chromitite seams during crystallization. Olivine-chromite cumulates in the second magma pulse contain twice as many chromite crystals per unit area as the first magma pulse. This suggests that the second magma pulse was more chrome-rich and/or more primitive in composition. The third magma pulse did not generate a chromitite seam even though chromite crystal abundance in olivine-chromite cumulates of the third magma pulse is comparable to the first and second magma influxes. Chromite crystal abundance in the chromitite seams is less than an order of magnitude greater than that in olivine-chromite cumulates immediately adjacent to the chromitites. In addition chromite crystal abundance per unit area decreases in a regular manner stratigraphically upward and downward from the chromitite seam. Chromite crystal abundance in olivine-chromite cumulates ranges from 35/cm<sup>2</sup> to over 300/cm<sup>2</sup> while chromite cumulates range from 2,000 to 3,500 per square centimeter.

The average chromite crystal size increases uniformly upward from the base of an individual olivine-chromite unit up to and including the enclosed chromitite seam. Immediately above the chromitite seam there is an abrupt decrease in the average chromite crystal size followed by a uniform increase in crystal size to the top of the unit. The documented variation and distribution in chromite crystal size indicate that neither gravity settling nor fluid flow phenomena in a liquid plus suspended crystals system are factors in chromitite formation. The chromite data also suggest that mixing of different or similar magmas was not a major factor in, or responsible for, chromitite formation in the Stillwater Complex as suggested by (3) and (4).

All olivine crystals were characterized according to size, setting, distribution, and enclosing or adjacent silicate phases in a selected number of thin sections. Olivine crystal abundance per unit area parallels that of chromite crystal abundance. In general olivine crystal size variation also parallels that of chromite although a more complex pattern is present immediately adjacent to enclosed chromitite seams. The documented upward increase in olivine grain size above a chromitite seam could be ascribed, at least in part, to accumulate overgrowth. Although no definite conclusion regarding gravity settling of olivine can be made, no observations or measurements were made that support gravity settling of olivine. In addition the actual number of olivine crystals within orthopyroxene oikocrysts is similar to the number of olivine crystals in equivalent areas where olivine is surrounded by plagioclase. This suggests either that homogeneous saturation and nucleation of olivine was a primary crystallization process or that olivine nucleation was controlled by the homogeneous nucleation of chromite (i. e. that chromite crystals served as nucleation points).

In summary, the physical occurrence, distribution, and size variation of chromite and olivine suggest that cyclic units and enclosed chromitites in the Peridotite zone of the Stillwater complex form essentially *in situ* as a result of physical and chemical processes and crystallization that occur within, and as a result of, a single magma pulse or influx. The data do not support the origin of chromitites and cyclic units from mixing of dissimilar magmas, mixing of similar magmas, or magma hybridization as suggested by (3) and (4).

(1) Campbell, I.H., 1987, *Journal of Geology*, v. 95, p. 35-54.

(2) Morse, S.A., 1986, *Journal of Petrology*, v. 27, p. 1183-1214.

(3) Irvine, T.N. & Sharpe, M.R., 1986, *Metallogeny of Basic and Ultrabasic Rocks*, Gallagher, M. J. and others, eds., London, England, Imperial University Institute of Mining and Metallurgy, p. 183-198.

(4) Raedeke, L.D. & McCallum, I.S., 1984, *Journal of Petrology*, v. 25, p. 395-420.