OLIVINES IN MAGNESIAN PORPHYRITIC CHONDRULES: MANTLE MATERIAL OF EARLIER GENERATIONS OF DIFFERENTIATED PLANETESIMALS? G. Libourel1,2, A.N. Krot1, M. Chaussidon1, L. Tissandier1, CRPG-CNRS 15, Rue Notre-Dame des Pauvres, BP20, 54501 Vandoeuvre les Nancy, France (libou@crpg.cnrs-nancy.fr), Hawai’i Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawai’i at Manoa, Honolulu, HI 96822, USA.

Introduction: It is generally inferred that chondrules formed about 4.56 billion years ago within 5 AU from the proto-Sun as solidified melt droplets freely floating in space by melting of fine-grained solid precursor materials, and that during these melting events chondrules behaved as closed systems, both chemically and isotopically; i.e., the observed range in chondrule bulk chemistry and modal mineralogy was entirely inherited from solid precursor materials that experienced melting to various degrees followed by igneous crystallization [1,2]. Shock-wave heating is currently considered to be the most plausible chondrule-forming mechanism [3].

From a detailed study of the petrography and chemistry of magnesium-rich (Fa and Fs <5 mol%), porphyritic (Type I) chondrules from the LL3.0 ordinary chondrite Semarkona and several CR2 carbonaceous chondrites focused on several chemical and mineralogical properties of Type I chondrules – compositions of chondrule glasses, mineralogical zoning, lack of equilibrium between olivine grains and chondrule glasses, lack of mass-dependent chemical fractionation, evidence for oxygen isotope exchange between chondrule melts and surrounding nebular gas – we have shown [4-7] that most of these features are inconsistent with closed-system crystallization of chondrule melts. The most compelling evidence against closed-system crystallization of chondrules comes from the chondrule glass compositions. When plotted on appropriate phase diagram (Fig. 1), chondrule glasses form a well-defined linear trend that is outside the olivine saturation field, inconsistent with liquid lines of descent controlled by olivine crystallization. These observations indicate that crystallization of olivine (and low-Ca pyroxene) does not control the composition of Type I chondrule mesostases, and therefore, a closed-system crystallization of chondrule melts is not a viable model for chondrule formation.

We suggested instead that melt compositions of Type I chondrules have been controlled by the surrounding nebular gas and that evolution of chondrule melt compositions resulted mainly from high-temperature gas-melt interaction under high partial pressure of gaseous SiO. Depending on the temperature at which such an interaction takes place and its duration, changes in the melt composition may lead to crystallization of new phases, when saturation is reached (preferentially low-Ca pyroxene and silica), and/or to the dissolution of pre-existing phases, which are no longer in equilibrium (mainly olivine). Since transport of elements from the gaseous interface into the melt, crystal nucleation/growth and phase dissolution are all diffusion limited and kinetically controlled, the present model may account for most of the mineralogical, chemical and isotopic features of Type I chondrules listed above, including the prominent lack of equilibrium between olivine grains and chondrule glasses. If correct, the main issue is now to address the origin of olivines in magnesian chondrules.

Results: Our petrologic survey of Type I chondrules in the CV carbonaceous chondrite Vigaran13 revealed the presence of olivine-rich aggregates showing granoblastic textures and composed of coarse-grained forsteritic olivines and Fe-Ni-metal nodules (Fig. 2). Such textures are easily recognizable in optical microscope using transmitted cross-polarized light, but can be missed if studied only in back-scattered electron images using scanning electron micro-

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Fig. 1. Chemical compositions (in wt%) of melt inclusions and glassy mesostases in Type I chondrules from Semarkona and CR carbonaceous chondrites [6, 8-10]. a) CaO vs. SiO2. b) Al2O3 vs. SiO2. c) Al2O3 vs. TiO2 in glasses of two chemically-zoned chondrules from Semarkona and PCA91082 (CR). Representative bulk compositions of Type I chondrules from Semarkona [8,9] are plotted (crosses: PO chondrules; crossed squares: POP and PP chondrules). Black solid lines represent modeled or experimentol olivine- and/or low-Ca pyroxene-saturated liquid lines of descent.
boundaries in lithic clasts are separated by thin layers of glass (i.e., wet), whereas others remain dry. Olivine grains with wet contacts have rounded outlines, indicating dissolution in chondrule glass. The aggregates are surrounded by shells of low-Ca pyroxene and glassy mesostasis, commonly observed in Type I chondrules in ordinary and carbonaceous chondrites, and by fine-grained, matrix-like rims (Fig. 2).

Discussion: Our discovery of relict, olivine-dominant, lithic clasts inside Type I chondrules may indicate that olivine-rich cores of at least some of Type I chondrules are remnants of olivine-dominated lithic fragments that experienced melt infiltration accompanied by dissolution and recrystallization of olivine grains. This interpretation could explain why chondrule melts are not in chemical equilibrium with olivine grains. Due to low-Ca pyroxene saturation and enrichment of the late chondrule melts in silica, olivines from the aggregates are no longer stable and dissolve, as indicated by rounded corrosion embayments at olivine grain edges (Fig. 2). Although some of the olivine grains in Type I chondrules have faceted outlines, the presence of such olivines is not incompatible with dissolution process; e.g., they could have resulted from olivine overgrowth acquired upon cooling during boundary layer crystallization of otherwise dissolving olivine grains. Driven by both interfaceal energy minimization and olivine dissolution, melt infiltration will proceed into the olivine aggregates insulating olivine grains (and metal nodules) into a glassy mesostasis in which low-Ca pyroxenes may eventually crystallized, leading ultimately to classical porphyritic olivine and porphyritic olivine-pyroxene chondrule textures.

Formation of the granoblastic textures requires sintering and prolonged, high-temperature (>1000°C) annealing – conditions which are not expected in the solar nebula during chondrule formation, but could have been achieved on parent bodies of olivine-rich differentiated meteorites e.g., ureilites and brachinites. We conclude that the lithic fragments in CV chondrules are relict grains resulting from fragmentation of unidentified differentiated planetesimals.

Conclusions: Magnesian Type I chondrules are thus complex objects composed of an inherited component, mainly forsteritic olivine and Fe-Ni-metal, originating from olivine-dominated (dunite-like) mantle material of earlier generations of differentiated planetesimals, and an igneous component equilibrated with nebular gas – glass, low-Ca pyroxene, high-Ca pyroxene, and silica phase. This implies that Type I chondrules are not as pristine as conventionally viewed; they consist of nebular and asteroidal materials and must have postdated accretion and differentiation of some early generation planetesimals. This finding is also supported by measurements of oxygen and magnesium isotopic compositions of olivines, pyroxene and glasses in magnesium-rich porphyritic olivine and porphyritic olivine-pyroxene chondrules [11].