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Origin of glass inclusions hosted in magnesian porphyritic olivines chondrules: Deciphering planetesimal compositions

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ABSTRACT

Glass inclusions occur in the most primitive magnesian porphyritic olivines of chondrules formed very early in the solar system, and understanding their formation and preservation is crucial for explaining early solar system evolution. Several different and frequently opposed models have been proposed to explain the origin of these glass inclusions and their host olivines, ranging from condensation processes in the nebula to crystallization products of chondrule melts. However, none of these models fully satisfy all the petrographic, chemical and isotopic observations. In this experimental work, we show that the peculiar compositions of these inclusions that exhibit significant chemical disequilibrium between glass and host olivine result from the slow crystallization of metastable olivines from a magma. The inhibition of plagioclase nucleation resulting in metastable olivine crystallization instead of the equilibrium assemblage (anorthite + clinopyroxene) is a natural consequence of the high liquidus temperature of the magma. This result implies a restricted compositional range for the parental magmas of these melt inclusions. Olivine phenocrysts inside type IA chondrules are thus interpreted as fragments of magmatic cumulates formed in magma ocean-like environments on fully or partially molten planetesimals. In a similar manner as for terrestrial rocks, studies of melt inclusions, giving information about the earliest magma oceans, could open a new way of assessing the evolution of the earliest bodies of the Solar System.

1. Introduction

Glass inclusions trapped in the most primitive olivines of Type 1A porphyritic olivine (PO) chondrules from CR and CV chondrites, can be classified into three groups based on their compositions: Al-rich, Al-poor and Na-rich inclusions (Varela et al., 2002). The latter two groups are presumed to result from exchanges with nebular gases during a late or secondary process. Indeed, Al-poor glass inclusions, as well as necked inclusions (open glass inclusions) and mesostases, are enriched in Si compared to Al-rich glass inclusions (Varela et al., 2005). These observations are consistent with mineral zonation of POP chondrules where orthopyroxene crystals and, sometimes silica phases, are systematically located at the rim of chondrules (Krot et al., 2004) and, with chondrule mesostasis that is zoned with decreasing concentration of Si toward the center of the chondrule (Libourel et al., 2003; Matsunami et al., 1993). These two types of zonation are interpreted as late interaction of chondrules with nebular gases (Libourel et al., 2006) and, they have even been experimentally reproduced by exposing a partially melted chip of chondrite to a SiO gas (Tissandier et al., 2002). Similarly chondrule mesostasis displays sometimes Na zonation with decreasing concentration of Na toward the center of the chondrule (Matsunami et al., 1993). Moreover Na-rich glass inclusions are usually devitrified (Varela et al., 2002) and glass inclusions in contact with fractures are enriched in Na (Varela et al., 2005) also suggesting a late interaction between glass and Na vapor (Sears et al., 1996). Therefore, combination of observations performed at chondrule or glass inclusions scales suggest that only Al-rich glass inclusions (hereafter called AGI) can be considered as pristine without ambiguity.

AGI compositions can be reliably plotted in the $CaO–MgO–Al_2O_3–SiO_2$ (CMAS) phase diagram since these four oxides account for more than 97 wt.% of all the constituents. In particular, FeO content is very low (0.5 wt.% on average with a maximum of <2 wt.% in the Kaba meteorite: Varela et al., 2005). AGI bulk compositions lie close to a particular plane of the CMAS phase diagram: the forsterite–diopside–anorthite ternary diagram (Presnall et al., 1978), crossing the silica undersaturation/saturation plane (±16 wt.% SiO_2) with an average quartz normative value of 1.4 wt.% SiO_2.(Fig.1a). Moreover, AGI are located in or near the anorthite stability field as shown by McSween (1977), indicating that olivine is not their liquidus phase and that these glass inclusions are clearly out of equilibrium with their host olivines (Fig. 1b).

High temperature condensation has been used to explain this important disequilibrium (Fuchs et al., 1973; Grossman and Olsen,

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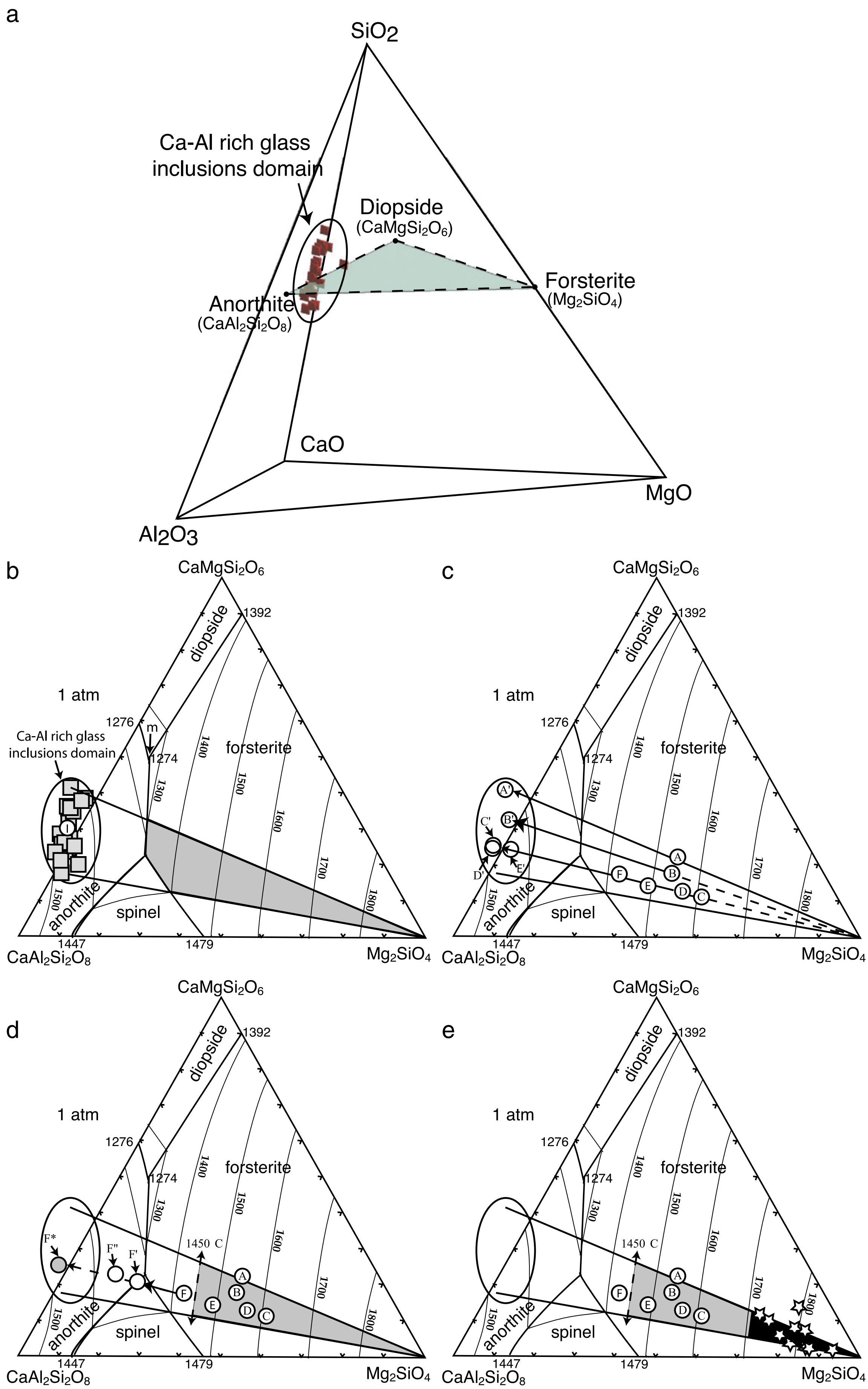
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