Identification of relict forsterite grains in forsterite-rich chondrules from the Mokoia CV3 carbonaceous chondrite

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ABSTRACT

Magnesium-rich forsterite grains (>Fo98) in FeO-poor chondrules show variations in cathodoluminescence (CL) intensity that are associated closely with variations in Al2O3 and TiO2 contents. CL thus can be used to map the distribution of Al and Ti in individual grains. We describe several categories of CL distribution, including grains that are homogeneous, grains that are zoned continuously, grains that show oscillatory zoning, and grains that show a heterogeneous distribution of CL intensity. Heterogeneous CL intensity is interpreted as the result of disequilibrium growth from the chondrule melt. CL surveys of individual chondrules help to identify forsterite grains that are potentially relics in their host chondrules, i.e., grains that did not crystallize in situ from the chondrule melt. Several of these grains show minor-element variations that differ from the majority of melt-grown grains in their host chondrules: this observation supports the inference that they are relics. Little evidence exists for growth of individual grains in multiple brief heating episodes. Identification of the abundance of relict grains is important for determining the thermal histories of chondrules as well as the nature of the precursor assemblages from which they formed.

Keywords: chondrites, chondrules, forsterite, cathodoluminescence

INTRODUCTION

Chondrules are millimeter-sized, ferromagnesian, spherical objects that are the most abundant constituent of chondritic meteorites. Although they are generally believed to represent the result of almost complete melting, there has been considerable discussion recently about the extent of melting that individual objects experienced, especially for porphyritic chondrules in which relict grains that survived melting are known to occur (e.g., Wasson and Rubin 2003; Hewins and Fox 2004; Connolly and Jones 2005; Hewins et al. 2005). Cooling rates for such chondrules are of the order of 10–100 °C/h from peak temperatures close to the liquidus (e.g., Hewins et al. 2005). Porphyritic olivine textures have been shown to require heterogeneous nucleation (Lofgren 1996; Connolly et al. 1998; Lofgren and Le 2000; Hewins and Fox 2004), but there is discussion about the size of relict grains necessary for production of the observed textures. There is a possibility that phenocrysts observed in chondrules may consist largely of relict material inherited from the chondrule precursor, with minimal overgrowth material from the host chondrule melt during the final melting episode. A better understanding of the proportions of relict material in porphyritic chondrules would help to resolve both the thermal histories they have undergone and the nature of precursor material preserved as relict grains.

The most abundant type of porphyritic chondrule in carbonaceous chondrites is referred to as “Type I”. These are chemically reduced assemblages that, in unaltered chondrites, contain forsterite, enstatite, Fe-Ni metal, and a Ca-Al-rich, commonly glassy, mesostasis. The phenocryst assemblage is predominantly forsterite in Type IA chondrules, a more equal abundance of forsterite and enstatite in Type IAB chondrules, and predominantly enstatite in Type IB chondrules. Forsterite and enstatite in type I chondrules commonly have low FeO contents (<2 mol% Fa). They therefore typically exhibit cathodoluminescence (CL), which is quenched in olivine with >~2 mol% Fa. Cathodoluminescence is a useful tool for examining the minor-element distribution in forsterite grains from type I chondrules (e.g., Steele et al. 1985; Steele 1986a, 1986b, 1995; Pack et al. 2004, 2005). As part of a broad study of a suite of chondrules from the Mokoia CV3 carbonaceous chondrite (Jones et al. 2004), we have carried out a CL and electron-microprobe survey of minor-element distributions in low-FeO chondrule forsterites, to gain further insights into the extent and distribution of relict grains and the nature of the chondrule formation process.

ANALYTICAL TECHNIQUES

A suite of over 90 chondrules was disaggregated from the Mokoia meteorite for bulk-chemical analysis (Schilk 1991). Polished mounts were prepared from 22 of the largest chondrules for further petrologic and isotopic studies (Jones et al. 2004). Eight of the 22 chondrules are described in this paper: these were selected because they contain olivine that exhibits CL. Scanning electron microscopy (SEM) and CL imaging were performed on a JEOL 5800LV SEM. The CL detector measures only intensity, and does not give wavelength information. The detector has a total wavelength response of 280 to 900 nm, with peak response at 600 nm. Electron-microprobe analyses were obtained using a JEOL 733 Superprobe and (more recently) a JEOL 8200 microprobe. X-ray mapping was carried out using the latter instrument. All these instruments are or were housed in the Electron Microbeam Facility in the Department of Earth and Planetary Sciences and Institute of Meteoritics, University of New Mexico.

RESULTS

Petrography

We carried out a detailed CL survey of low-FeO forsterite in eight chondrules: 11, 12, 25, 34, 70, 7C, 10C, and 14C (Fig. 1).