A unique glimpse into asteroidal melting processes in the early solar system from the Graves Nunatak 06128/06129 achondrites

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ABSTRACT

The recently recovered Antarctic achondrites Graves Nunatak 06128 and 06129 are unique meteorites that represent high-temperature asteroidal processes in the early solar system never before identified in any other meteorite. They represent products of early planetesimal melting (4564.25 ± 0.21 Ma) and subsequent metamorphism of an unsampled geochemical reservoir from an asteroid that has characteristics similar to the brachinite parent body. This melting event is unlike those predicted by previous experimental or geochemical studies, and indicates either disequilibrium melting of chondritic material or melting of chondritic material under volatile-rich conditions.

Keywords: Achondrites, brachinites, planetesimal melting, asteroids, Al-Mg chronometer

INTRODUCTION

Achondritic meteorites commonly represent remnants of magmatic systems from differentiated planets (e.g., Moon, Mars) or asteroids (e.g., 4 Vesta). They may be products of early whole planetary body melting such as the lunar ferroan anorthosites, residuum of low degrees of melting and melt extraction such as the acapulcoites and lodranites, or products of episodic mantle partial melting such as lunar and Martian basalts. Newly discovered paired achondritic meteorites Graves Nunatak (GRA) 06128 and 06129 are mineralogically distinct from all of the other known achondrites and do not fit within the planetary or petrologic context of any known parent body. Specifically, these meteorites have a high abundance of sodic plagioclase and Fe-rich silicates, implying they have experienced more elemental fractionation and are more “evolved” than other planetary lithologies such as basalts from the Moon, Mars, or 4 Vesta. Superimposed on this distinct high-temperature mineral assemblage is a high-temperature metamorphism and low-temperature alteration. As discussed below, these unique characteristics are inferred to result from asteroidal processes in the early solar system unlike those recorded in any other meteorites of asteroidal or planetary origin.

SAMPLE DESCRIPTION

Paired meteorites GRA 06129 and GRA 06128 (hereafter, GRA) exhibit a heterogeneous, granoblastic texture (Fig. 1) with a modal mineralogy dominated by sodic plagioclase (~81 vol%). The plagioclase exhibits a limited range in composition from An85Ab0.5Or1 to An75Ab1.0Or1. Two pyroxenes (orthopyroxene and Ca-rich clinopyroxene) and olivine are the most abundant silicates after plagioclase, making up approximately 9 and 8% of the rock, respectively. The composition of olivine is fairly homogenous at Fo41–42 and Cr2O3 values from 0.00–0.07 wt%. One olivine grain, adjacent to a spinel, has slightly higher Fo (Fo42–44) and Cr2O3 (0.02–0.31 wt%) contents, suggesting this compositional variability is related to subsolidus re-equilibration with the adjacent spinel grain. Olivine contains inclusions of Fe-Ni metal, troilite, and pentlandite. Troilite and pentlandite are commonly intergrown with small blobs or blades of Fe-Ni metal (64–68 wt% Ni), spatially associated with the pentlandite. These inclusions appear to be trapped sulfide melt that has undergone subsolidus re-equilibration. The high-Ca pyroxene ranges in composition from En35Fs38Wo29 to En44Fs33Wo23. Most pyroxene grains exhibit exsolution of low-Ca pyroxene lamellae that are 2 to 8 µm in width. The average composition of the orthopyroxene is En35Fs38Wo23. Based on the stoichiometry of ~100 electron microprobe analyses, the average ferric iron (Fe3+/Fe3+ + Fe2+) in the high-Ca pyroxene is 7%. Apatite overgrowths on merrillite (dehydrogenated whitlockite) occur in individual phosphate masses up to 600 µm in size. Apatite is halogen-rich (Cl ~5.0 wt%, F ~0.7 wt%), whereas the merrillite is halogen-poor with substantial Na in the CaH4 site (~2.5%). The modal abundance of phosphates is ~1.0%. Ilmenite and “spinel” are commonly intergrown and are distributed throughout the section in trace abundances.

A megascopic view of the GRA meteorites indicates they