CHEMICAL AND ISOTOPIC CONSTRAINTS ON THE FORMATION AND EVOLUTION OF SA-1, A BASALTIC CAI FROM ALLENDE

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Studies of the chemical and isotopic compositions of minerals and of partitioning of trace elements within CAI [1-3] provide constraints on formation mechanisms and subsequent evolution. CAI with basaltic texture and mineralogy are unusual in Allende; however, these CAI may represent differentiated material from a planetary environment and can provide information on igneous processes prior to the aggregation of Allende.

We used the PANURGE ion microprobe to study the partitioning of trace elements and the Mg isotopic composition of phases within SA-1, a coarse-grained Allende CAI which has a basaltic texture and mineralogy. The data allow us to: 1) test whether equilibrium closed system crystallization explains the partitioning of trace elements between phases, 2) check for excess ^{26}Mg and intrinsic mass fractionation, 3) constrain possible formation processes, and 4) calculate an initial trace element composition for the SA-1 parental liquid.

SA-1 resembles a lunar basalt with a subophitic texture and contains clinopyroxene, plagioclase, Mg-rich pigeonite, spinel, olivine, nepheline, sodalite and opaque assemblages [4]. We analyzed clinopyroxene, plagioclase, pigeonite and nepheline for rare earth elements (REE), Ba, Sc, Ti and transition elements V, Cr, Mn and Fe (Figs. 1, 2). Trace element and Mg isotope data were collected using methods and standards described in [3] and [5].

Clinopyroxene is depleted in the LREE (1.5-8× chondritic (ch)) and Eu (2-7×ch) relative to the HREE (6-50×ch). Both plagioclase and nepheline have LREE-enriched REE patterns. However, nepheline has a negative Eu anomaly and plagioclase a positive Eu anomaly. Plagioclase shows an extreme range of REE abundances. Large plagioclase from the interior have very low REE with 1-2×ch LREE and 0.3-1×ch HREE. Small plagioclase laths have up to 70×ch LREE and 60×ch HREE. Nepheline, a late crystallizing phase, has 18-70×ch LREE and 15-60×ch HREE. Pigeonite has a U-shaped REE pattern, a negative Eu anomaly and a large range of concentrations. Cores of large pigeonite are highly depleted in REE (<0.3×ch for all REE), while pigeonite overgrowths have up to 20×ch REE. Literature partition coefficients for low Ca pyroxene [6] predict similar LREE-depleted REE patterns for pigeonite and clinopyroxene. Pigeonite is not LREE-depleted in SA-1 and is more typical of orthopyroxene from lherzolites [7] and ureilites [8].

Ba increases consistently with the degree of crystallization; concentration ranges are plagioclase (4-78ppm), clinopyroxene (0.3-9 ppm), pigeonite (0.4-14ppm) and nepheline (4-8ppm). In contrast to the predictable increase of incompatible trace elements during crystallization, the distribution of compatible trace elements (Sc, V, Mn, Ti) is inconsistent with equilibrium partitioning. Erratic compatible trace element zoning profiles are common and extreme variation of concentration levels occurs within and between crystals of the same phase. For example, in pyroxene concentration ranges are Sc (10-160 ppm), V (1-2500ppm), Cr (400-12,000ppm) and Ti (200-11,000ppm). Kinetic effects due to rapid crystallization and compositional variation of partition coefficients appear to be controlling the partitioning of compatible elements.

The Mg isotopic compositions are expressed as $\delta^{26}Mg$ relative to 0.13955 and as F_{Mg} calculated from $^{25}Mg/^{24}Mg$ ratios relative to values measured in standards. The cores of large calcic (An90-98) plagioclase show no excess ^{26}Mg ($\delta^{26}Mg=0.9\pm3.5°/\circ\circ$). Plagioclase and augite show evidence of isotopically heavy Mg ($F_{Mg}=3.0\pm1.5°/\circ\circ/amu$). The data give an upper limit to $^{26}Mg^{*}/^{27}Al$ of

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$<1.6\times10^{-6}$. There is no evidence for any isotopic variability between the mantle and interior of SA-1.

The complementary REE patterns and Eu anomalies and the enrichment of incompatible trace elements in ground mass phases is consistent with closed system crystallization of SA-1. The lowest incompatible element abundances are found in augite crystals in the outer margin of SA-1. This, and the identical isotopic composition of interior and mantle phases, argues for crystallization from a homogeneous melt of the mantle prior to the interior. Assuming the most trace element depleted clinopyroxene from the outer margin is the first phase to crystallize, it is possible to calculate an initial liquid composition using equilibrium partition coefficients for Ba and the REE. The initial melt has LREE ~15×ch, HREE ~10×ch and Ba~20×ch. This REE pattern resembles group I [7]. However, a pronounced positive Ce anomaly, a small positive Sm anomaly and a LREE-enriched pattern require a 2-stage evolution for SA-1.

Refs. [1] Crozaz et al. (1988) LPSC XIX, 231; [2] Fahey et al. (1987) GCA 51, 3215; [3] Beckett et al. (1989) GCA, submitted; [4] Boctor et al. (1989) this volume; [5] Hutcheon et al. (1987) GCA 51, 3175; [6] Fujimaki et al. (1984) JGR 89, B662; [7] Frey (1983) and [8] Boynton (1983), both in Rare Earth Elements in Geochemistry 2, Elsevier. (#659)

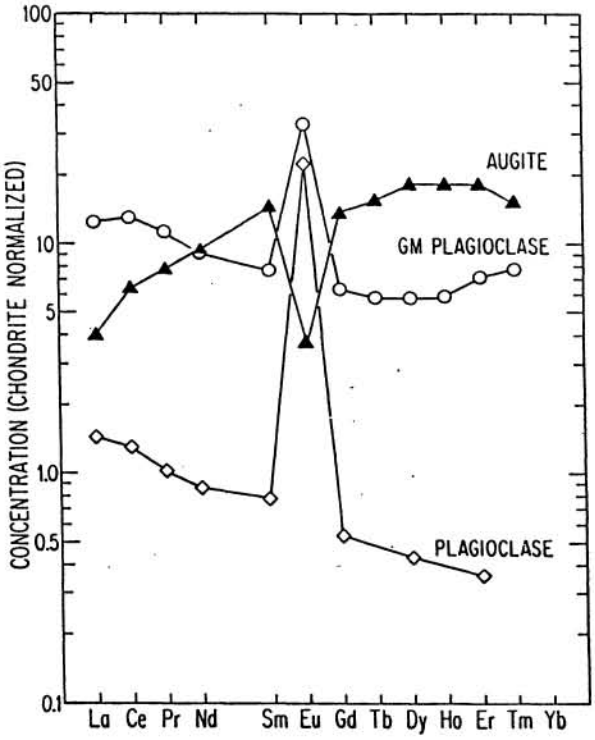

Fig. 1. REE patterns for plagioclase and clinopyroxene in SA-1.

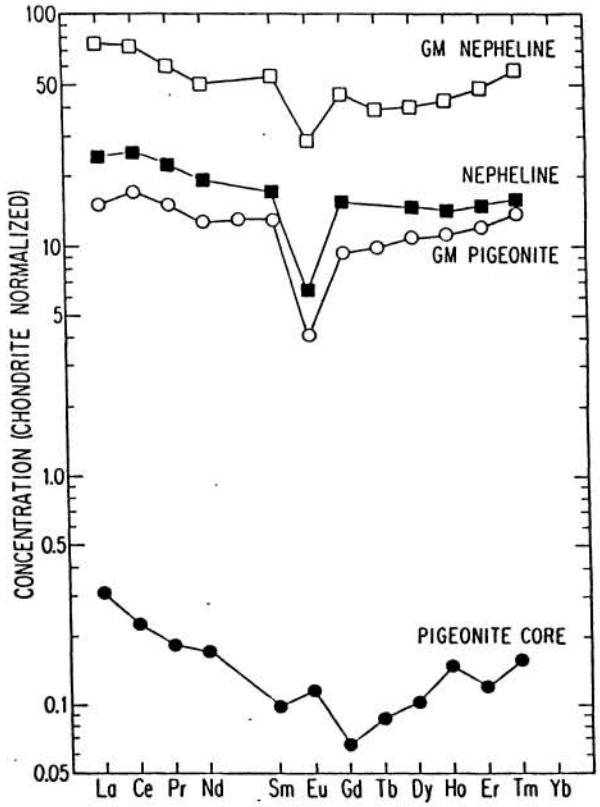

Fig. 2. REE patterns for pigeonite and nepheline in SA-1.

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