Rb–Sr ISOTOPIC SYSTEMATICS OF ALKALI-RICH FRAGMENTS IN THE YAMATO–74442 LL–CHONDRITIC BRECCIA.

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Introduction:

Alkali-rich igneous fragments were identified in the brecciated LL-chondrites, Krähenberg (LL5) [1], Bhola (LL3–6) [2], and Yamato (Y)–74442 (LL4) [3–5], and show characteristic fractionation patterns of alkaline elements [6]. The K–Rb–Cs-rich fragments in Krähenberg, Bhola, and Y-74442 are very similar in mineralogy and petrography (olivine + pyroxene + glass), suggesting that they could have come from related precursor materials [5]. We have undertaken Rb–Sr isotopic studies on alkali-rich fragments in Y–74442 to precisely determine their crystallization ages and the isotopic signatures of their precursor material(s).

Results:

The Rb–Sr data for nine alkali-rich fragments yield an age of 4429 ± 54 Ma (2σ error) for $\lambda(^{87}\mathrm{Rb}) = 0.01402\ \mathrm{Ga}^{-1}$ with an initial ratio of $^{87}\mathrm{Sr}/^{86}\mathrm{Sr} = 0.7144 \pm 0.0094$ (2σ error) using the Isoplot/Ex program (Fig. 1) [7]. The measured Rb–Sr age is distinctly younger than the primary Rb–Sr age of 4541 ± 14 Ma of LL-chondrite whole-rock (WR) samples [8]. The well-behaved Rb–Sr isotopic systematics of the fragments reported herein, coupled with those of the host meteorite, strongly suggest that the fragments were not disturbed by thermal metamorphism or by impact heating on an LL-chondrite parent body at 4200–4400 Ma [9]. Remarkably, the initial ratio of $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ for the Y–74442 fragments is much higher than that of LL-chondrite WRs (0.699015 ± 0.000076 [8]). The data point of Y–74442 WR deviates –140 ε-units from the best-fit line.

Discussion:

There is no correlation between $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratios and strontium contents in the fragments, indicating that the wide range in Rb/Sr and a linear trend observed in the Rb–Sr isochron diagram are not due to mixing (alkali-rich glass and other phases). We thus interpret the obtained age of 4429 ± 54 Ma to indicate that the fragments crystallized from a melt at 4429 Ma, and that their Rb–Sr isotopic system was not affected by thermal and/or shock metamorphisms.

Evolution of early Solar System reservoirs including those related to Y–74442 fragments can be understood by plotting the Rb–Sr ages and corresponding initial ratios of $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ on a time (T) versus initial $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ (I_{Sr}) diagram (Fig. 2). We assume that precursors of planetary material formed at $T_0 = 4568$ Ma [10] with $I_{Sr} = 0.69889$ [i.e. the solar nebula was homogeneous in terms of strontium isotope composition [11], and equal to that of CAIs]. A time-averaged Rb/Sr value for LL-chondritic materials is calculated to be 0.107 [8], which is much smaller than the solar Rb/Sr value (0.467), or CI-chondrites value (0.296). Similarly, a time-averaged Rb/Sr value of the source material for the alkali-rich fragments in Y–74442 is calculated to be 2.58. Given the relatively young Rb–Sr age of 4429 Ma, explanation of the high Rb/Sr ratio requires very early enrichment of rubidium. The Rb/Sr ratios for the alkali-rich fragments vary from 2.28 (Y–74442,130–7) to 15.1 (Y–74442,121–7) simply due to an unrepresentative sampling for alkali-rich groundmass glass.

The bulk chemistry of the alkali-rich fragments [1,5,6] does not support differentiation from the host chondritic material prior to 4429 Ma ago. Elemental abundances of the fragments are almost identical to those of the host chondrite or unequilibrated ordinary chondrite (UOC) chondrules except for the alkali fractionations.

We must therefore invoke an alternative two-component mixing model where one is highly enriched in alkalis and the other one component is a ferromagnesian component (olivine + pyroxene) depleted in siderophile and chalcophile elements [2]. We consider mixtures of two components A (alkali condensates) and B (chondritic ferromagnesian silicates) having not only different concentrations of rubidium and strontium but also different $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratios. This model assumes that at 4429 Ma the $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratios of the chondritic component and the mixture are 0.69952 and 0.7144, respectively. We estimated that strontium contents in the component A and B are 0.1–10 ppm and ~10 ppm, respectively. Rubidium content in component A varies from 100 ppm to 5000 ppm, because the strontium and rubidium contents of the alkali-rich fragments are approximately 10 ppm and 100 ppm, respectively. As a result, a realistic Rb/Sr ratio of component A is >300 and valid A to B mixing ratios are about 10:90 (Fig. 2).

Both the $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratio of 0.7144 at 4429 Ma and the forty-fold enrichments of rubidium in the fragments at present can be explained in terms of an admixture of an exotic alkali component and chondritic material with appropriate weight ratios (i.e., 10:90). The two components may have mixed ~ 44 to 180 Mas after the initial assembly and accretion of a chondritic parent body possibly by flash melting induced by impact 4429 Ma ago.

Sodium chloride and potassium chloride brines in halite and sylvite crystals within the Monahans H-chondritic breccia possess high Rb/Sr = 15 and the very radiogenic strontium isotopic composition (^{87}Sr/^{86}Sr = 3.6 [12]). Some sylvite crystals contain ~500 ppm rubidium with the superchondritic K/Rb ratio of ~500 [13]. Although the sylvite endmember is estimated to contain ~1000 ppm of rubidium, K/Rb and possibly K/Cs ratios of the sylvite become extremely large. Thus, the aqueous fluids from an early solar system body ([12, 14]) that was undergoing cryovolcanism [15] are not appropriate end-members of alkalis, especially for the heavier ones.

An alternative explanation is one in which the enrichment represents alkali material condensed from the residual gas after removal of refractory strontium and magnesium silicates in the early solar nebula and would have long been isolated from other components. Carriers of such alkali-rich components may exist in the early solar nebula before chondrule formation and could be partly consumed as one of the precursor materials of ferromagnesian chondrules [16]. The potassium isotopic composition of Krähenberg alkali-rich fragments does not show detectable mass dependent fractionation and is identical to those of other Solar System objects [17], suggesting that the alkali-rich reservoir discussed here was not produced by a local event, but instead represents a remnant of nebula-wide fractionation.

The fragments in Krähenberg, Bhola, and Y–74442 show a characteristic alkali-fractionation pattern; sodium abundances are less than chondritic and heavier alkalis are superchondritic [1,6, and the present study]. This may be related to the condensation temperatures of alkali component(s) and/or the timing of removal of alkali-rich phase(s) from the nebular gas.

Conclusions:

We precisely determined the crystallization age of alkali-rich igneous fragments of the Y–74442 chondritic breccias; 4429 ± 54 Ma for $\lambda(^{87}\text{Rb}) = 0.01402\ \text{Ga}^{-1}$ with the high initial ratio of ^{87}Sr/^{86}Sr = 0.7144 ± 0.0094. The obtained age and initial ^{87}Sr/^{86}Sr isotopic signature suggest that 1) the alkali component would have condensed from the residual nebular gas after removal of refractory strontium and must have been isolated for a long time in a region where temperatures were sufficiently low to prevent reaction with other silicates/oxides, and 2) mixture of the alkali condensates and a ferromagnesian component could reflect flash heating induced by impact on a chondritic parent body 4430 Ma ago. In such a scenario the original textures of the nebular condensates of moderately volatile alkalis were modified by the later melting event. Nevertheless, a remarkable signature of early alkali enrichment by fractional condensation in the solar nebula has been preserved as a minor component of chondritic breccias.

References:

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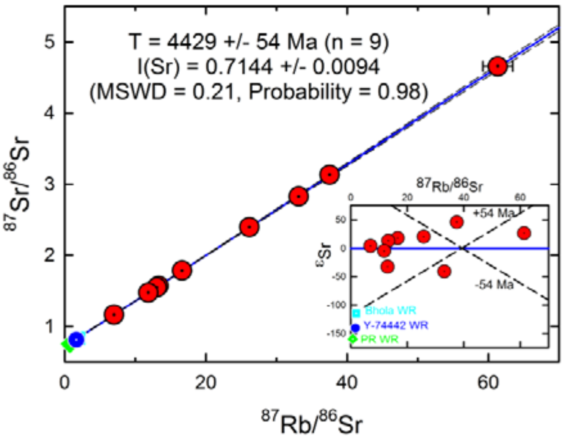

Fig. 1. Rubidium–strontium isochron diagram for alkali-rich igneous fragments in Y–74442. The inset shows deviations of ^{87}Sr/^{86}Sr in parts in 10^4 (ε–units) for Y–74442 alkali-rich fragments relative to the best-fit line. The ^{87}Sr/^{86}Sr errors are within the symbols. Whole-rock (WR) samples of Y–74442 (blue), Bhola (aqua), and Peace River (L6) (green) are also plotted for comparison.

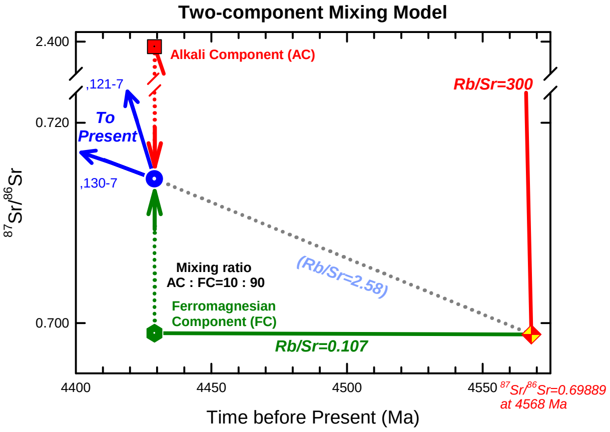

Fig. 2. Time (ages; Ma) versus initial ratio of ^{87}Sr/^{86}Sr evolution diagrams for alkali-rich fragments in Y–74442. A possible evolution of precursor materials of alkali-rich fragments in Y–74442. Both the Rb/Sr of 0.714 at 4429 Ma and forty-fold enrichments of rubidium in the fragments at present can be explained by mixture of two end-members: alkali component: Rb/Sr = 300, ^{87}Sr/^{86}Sr = 0.7553–2.392 at 4429 Ma and ferromagnesian component: Rb/Sr = 0.107, ^{87}Sr/^{86}Sr = 0.69945 at 4429 Ma, chondritic abundances of rubidium and strontium. The Rb/Sr ratios for the alkali-rich fragments vary from 2.28 (Y–74442,130–7) to 15.1 (Y–74442,121–7) simply due to an unrepresentative sampling for alkali-rich groundmass glass.