SILICA EXCESS IN ANORTHITIC PLAGIOCLASE FROM TYPE 3.00 CHONDRITE CHONDRULES: EVIDENCE FOR RETAINING PRIMARY ^{26}Al-^{26}Mg SYSTEMATICS. T. J. Tenner[1], T. Ushikubo[2], D. Nakashima[1], N.T. Kita[1], M.K. Weisberg[3,4], and M. Kimura[5,6]. [1]WiscSIMS, Dept. of Geoscience, Univ. of Wisconsin-Madison, USA (tenner@wisc.edu), [2]Institute for Core Sample Research, JAMSTEC, Kochi, Japan, [3]Kingsborough Community College and Graduate Center, CUNY, USA, [4]American Museum of Natural History, NY, USA, [5]Faculty of Science, Ibaraki University, Mito, Japan, [6]National Institute of Polar Research, Tokyo, Japan.

Introduction: Al-Mg isotope systematics of chondrules in primitive chondrites is used to determine the timing of chondrule formation in the protoplanetary disk [1]. It is often assumed that ^{26}Al ($\tau_{1/2}$: 0.705 Myr) was distributed homogeneously in the Solar nebula, with a canonical initial ($^{26}Al/^{27}Al)_0$ ratio of 5.2×10^{-5} determined from CV3 CAIs [2,3]; the validity of this assumption is actively debated [3-6].

A potential issue with this chronometer is the closure of the ^{26}Al-^{26}Mg system in chondrule plagioclase, which may have been disturbed by thermal metamorphism and/or aqueous alteration [7]. Here, we demonstrate that excess Si in anorthitic plagioclase in chondrules from type 3.00 chondrites indicates retainment of the primary ^{26}Al-^{26}Mg system.

Samples, Methods: Crystalline plagioclase, verified optically, in 20 chondrules/fragments (type I and/or FeO-poor) from CR3.00 [8] chondrite sections Meteorite Hills (MET) 00426,46 and Queen Alexandra Range (QUE) 99177,49 were measured by electron microprobe (EMP) analysis with the UW-Madison Cameca SX-51. Crystalline $An_{95,78,18}$ standards were used to determine Si, Al, Ca, and Na concentrations. At operating conditions (15 kV accelerating voltage, 10 nA beam current, focused beam) no Na migration occurred on the An_{18} standard. Mg was calibrated with synthetic forsterite; Ti, Mn, Fe, and K were also measured. Before and after unknowns, measurements of plagioclase standards revealed appropriate major element concentrations, 99.7-100.2 % totals, and 4.994 to 5.001 cations normalized to 8 O. Preliminary field emission scanning electron microscopy indicates CR3.00 chondrule plagioclase is free of inclusions. Additionally, we report anorthitic plagioclase data from 22 Acfer 094 (ungr. C3.00 [9]) chondrules/fragments (21 type I, 1 Al-rich); analytical methods are in [10]. Endmember components of all data shown were calculated using methods from [11].

Results, Discussion: In CR3.00 chondrules/fragments, oxide totals for plagioclase are 99.4 to 101.0 wt. % (15 to 40 spot analyses per chondrule). Molar An fractions (normalized to An, Ab, and K-feldspar) are 0.81 to 0.99. Cation totals are 4.921 to 5.013, the majority are appreciably below 5.000. In Acfer 094 chondrules/fragments, oxide totals for plagioclase are 98.7 to 101.2 wt. % (1 to 10 spot analyses per chondrule). Molar An fractions are 0.88 to 0.99. Cation totals are 4.935 to 5.031; the majority are appreciably below 5.000.

□Si_4O_8 substitution: Experiments [12] demonstrate that anorthite can incorporate up to several weight percent of silica solid solution at 1 atm. and 1200 to 1500 °C (Fig. 1), pending the liquid is sufficiently siliceous. It is commonly suggested this occurs via the coupled substitution □Si_4O_8, resulting in a vacancy and excess Si in the structure of anorthitic plagioclase; this substitution yields anomalously low cations. EMP data of plagioclase in lunar basalts indicate the presence of □Si_4O_8 [11]; using the same stoichiometric calculations, the majority of An-rich plagioclase measured in CR3.00 and Acfer 094 chondrules (34 of 42) also have a □Si_4O_8 component (Fig. 2). Differences in An and MgO contents between lunar and chondrule plagioclase (Figs. 2a,2b) are related to the bulk chemistry of liquids from which they crystallized.

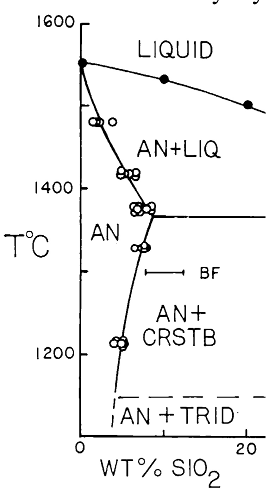

Fig. 1. Experimental data and phase diagram for the join anorthite-SiO_2 from [12]. Excess Si is accommodated in anorthitic plagioclase via the □Si_4O_8 structural substitution.

The presence of excess Si in CR3.00 and Acfer 094 chondrule plagioclase strongly indicates retention of primary, high temperature crystallization features. For example, low temperature (<200 °C) aqueous alteration of An-rich plagioclase forms phyllosilicates [13], and high temperature (400-600 °C) metamorphism involving Na causes An-rich plagioclase to form nepheline [14]. In both scenarios, excess Si in An-rich plagioclase would most likely be erased, and reactions involving MgO-bearing phases, like phlogopite [13], or olivine and/or pyroxene (e.g. eq. 4; [14]) could easily disturb their primary Mg.

Comparisons to other chondrule plagioclase: Chondrule anorthitic plagioclase from 3.01 to 3.05 L

[15], LL [16,17], and CO [18,19] chondrites generally exhibit excess Si (Fig. 2). A 1500 °C, 1 atm. experiment using type I CO chondrule analog starting material by [18] also produced An-rich plagioclase with excess Si (Fig. 2). However, plagioclase in chondrules from Yamato-81020 (CO3.05) have little to no excess Si, and are generally stoichiometric. Plagioclase in Al-rich chondrules from CR2 chondrites [20] have □Si_4O_8 contents similar to CR3.00 chondrule plagioclase (Fig. 2), suggesting minimal aqueous alteration.

Chondrule plagioclase in >3.05 L, LL, CO, and CV chondrites is comparatively depleted in Si [15,18,21-26]; increasing Si depletion correlates with decreasing An content (Fig. 2a). Such behavior is consistent with the often-observed presence of nepheline, due to alteration reaction. With a few exceptions, MgO contents of >3.05 chondrule plagioclase are generally lower than in 3.00-3.05 chondrule plagioclase (Fig. 2b); this could indicate Mg-loss during thermal metamorphism.

Implications for ^{26}Al-^{26}Mg systematics: Based on the presence of excess Si, we suggest An-rich plagioclase from 3.00-3.05 and CR2 chondrite chondrules retained their primary crystallization features, meaning their Al-Mg isotope systematics are robust. Assuming homogeneously distributed ^{26}Al in the Solar nebula, this implies chondrules from L, LL, CO, and Acfer 094 (ungr. C) chondrites formed ~1-3 Myr after CAIs [7,15-17,19,27-30]. Some CR2/CR3.00 chondrules also formed within this timeframe, but many formed >3 Myr after CAIs [31-36]. Many chondrules from 3.05-3.1 chondrites have resolvable excess ^{26}Mg, but lack excess Si in plagioclase [15,19,21]; this could indicate marginal alteration that did not disturb Mg. Additionally, several ordinary and carbonaceous chondrite chondrules from subtypes 3.1 to 3.4 have plagioclase with resolvable excess ^{26}Mg [7,34], but the majority from subtypes ≥3.4 do not (e.g. [7]). This could signify disturbed Mg in plagioclase from thermal metamorphism. Often, higher subtype chondrites have chondrules that appear to have avoided metamorphism (ex: in Kainsaz, 38% of chondrules have nepheline-free plagioclase; [22]). Investigating Si-excesses/deficits by EMP analysis could determine if plagioclase in such chondrules is suitable for Al-Mg isotope systematics.

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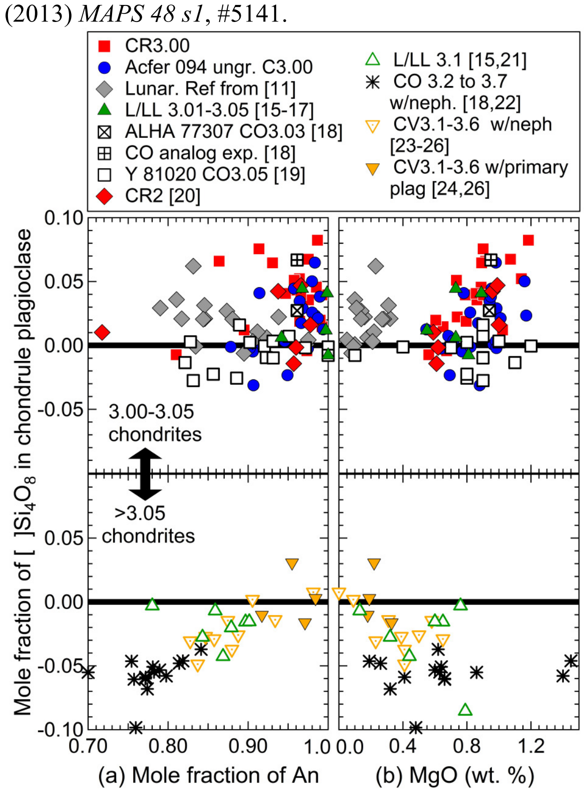

Fig. 2. Comparison of plagioclase (a) molar anorthite content (normalized to An + Ab + K-feldspar) and (b) MgO oxide weight percent, relative to molar □Si_4O_8 content in lunar samples and chondrite chondrules. For chondrules, each datum represents an averaged value per chondrule. □Si_4O_8 contents greater than 0 signify excess Si in plagioclase.