

**AL-MG ISOTOPIC SYSTEMATICS IN THE ANGRITE SAHARA 99555 AND THE PRIMITIVE ACHONDRITE BRACHINA.** L. Spivak-Birndorf<sup>1</sup>, M. Wadhwa<sup>1</sup>, P. E. Janney<sup>1</sup> and C. N. Foley<sup>1\*</sup>, <sup>1</sup>Isotope Geochemistry Laboratory, Department of Geology, The Field Museum, 1400 S. Lake Shore Dr., Chicago, IL 60605 (\*Present address: Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington DC, 20015).

**Introduction:** Understanding the role of the extinct radionuclide <sup>26</sup>Al ( $t_{1/2} \sim 0.72$  My) in the early solar system has long been an important problem in cosmochemistry. The <sup>26</sup>Al-<sup>26</sup>Mg decay system has been applied as a fine scale chronometer for early solar system events [1,2,3]. There has also been a long standing debate about the potential for <sup>26</sup>Al as a source of heat in the melting and differentiation of early solar system materials [4,5]. So far, definitive evidence for the in situ decay of <sup>26</sup>Al, inferred from excesses of its daughter isotope <sup>26</sup>Mg, has only been reported in a small number of differentiated meteorites [6-9].

We are continuing our investigation of Mg isotopic systematics in differentiated meteorites in order to better understand the possible role of <sup>26</sup>Al in planetesimal differentiation and the viability of the <sup>26</sup>Al-<sup>26</sup>Mg chronometer for dating early solar system events. We are also investigating the mass-dependent fractionation of Mg isotopes with high precision (typically better than  $\sim 0.05$  ‰  $\text{amu}^{-1}$ ) in these materials, which has only been possible with the advent of multi-collector ICP-source mass spectrometry (MC-ICPMS). We have previously reported Mg isotopic systematics in the eucrites Juvinas, Ibitira and A881394 [9]. Here, we have extended our study to include the angrite Sahara 99555 and the primitive achondrite Brachina. Angrites are a unique group of basaltic achondrites with ancient formation ages [10,11]. There is also evidence for old formation ages of the brachinites (e.g., [12]), which are olivine-rich primitive achondrites [13]. Also, evidence of live <sup>26</sup>Al has previously been reported in Sahara 99555 [8] and live <sup>53</sup>Mn has been demonstrated to have been present in both Sahara 99555 and Brachina [8,14,15]. Here we report high precision Mg isotopic compositions for pyroxene and plagioclase mineral separates and a bulk sample of Sahara 99555, as well for a pyroxene mineral separate and a bulk sample of Brachina. We are in the process of generating pure plagioclase separates from Brachina (which contains only  $\sim 10\%$  modal abundance of this mineral [13]) and plan to analyze these in the near future.

**Analytical Procedures:** Our analytical procedures were similar to those described previously [9]. Mineral separates were prepared by crushing interior chips ( $\sim 200$ - $250$  mg) in a boron carbide mortar followed by mineral separation using a Frantz magnetic separator

and purification of these separates by hand picking. Each separate, typically weighing a few mg, was digested in an HF/HNO<sub>3</sub> mixture. Full dissolution of each sample in dilute HNO<sub>3</sub> was achieved prior to Mg separation by cation exchange chromatography. Bulk sample chips weighing  $\sim 25$ - $75$  mg were also dissolved according to the same procedure. For each sample solution, a  $\sim 10\%$  aliquot was taken for measuring <sup>27</sup>Al/<sup>24</sup>Mg ratios before column chemistry was performed. All samples were passed through two cation exchange columns to ensure the isolation of Mg from various major matrix elements which can affect the measurement of the Mg isotopic composition during mass spectrometry. The total procedural blank for Mg was typically  $\sim 1$  ng or less and is negligible.

The clean Mg isolated from the mineral separates and bulk samples was diluted to a concentration of 0.5 ppm and analyzed using the Micromass Isoprobe MC-ICPMS at the Field Museum. A CETAC Aridus desolvating MCN was used to introduce solutions into the plasma. Instrumental mass fractionation was corrected using the sample-standard bracketing technique. To determine the excesses in <sup>26</sup>Mg from the decay of <sup>26</sup>Al (i.e.,  $\Delta^{26}\text{Mg}$ ), measured <sup>26</sup>Mg/<sup>24</sup>Mg ratios were mass bias corrected by normalization to a <sup>25</sup>Mg/<sup>24</sup>Mg ratio of 0.12663 [16] using the exponential law. Data reported in Figs. 1 and 2 represent the average of  $\sim 4$ - $20$  repeat measurements, usually measured on multiple days. All  $\delta^{25}\text{Mg}$  and  $\delta^{26}\text{Mg}$  values are reported as permil deviations relative to the new Mg isotopic standard DSM3, which is similar in composition to bulk carbonaceous chondrites [17].

**Results and Discussion:** Figure 1 shows the extent of mass dependent fractionation of Mg isotopes in minerals and bulk samples of Sahara 99555 and Brachina relative to the standard DSM3. Mg isotopic compositions of mineral separates and bulk samples of Sahara 99555 and Brachina vary by up to  $\sim 0.16$  ‰  $\text{amu}^{-1}$  relative DSM3 (Fig. 1). The solid line in Fig. 1 is the mass-dependent fractionation line defined by a variety of terrestrial samples analyzed in our laboratory (TFL). All of the mineral separates and bulk samples fall on this line, within error, with the notable exception of Sahara 99555 plagioclase separates, which show resolvable excesses in <sup>26</sup>Mg and thus lie to the right of the TFL. It should be noted that our measured  $\delta^{25}\text{Mg}$  and  $\delta^{26}\text{Mg}$  values relative to the DSM3 standard

for the Sahara 99555 bulk sample are somewhat lighter (i.e., by  $\sim 0.15\%$  amu<sup>-1</sup>) than those reported by [18]. The reason for this apparent discrepancy is not clear at this time.

Figure 2 shows the  $\Delta^{26}\text{Mg}$  plotted versus  $^{27}\text{Al}/^{24}\text{Mg}$  ratios in the pyroxene and plagioclase mineral separates and bulk rock sample of the Sahara 99555 angrite. The two plagioclase fractions we generated by magnetic separation and hand picking have almost identically low  $^{27}\text{Al}/^{24}\text{Mg}$  ratios. Visual inspection of these separates prior to dissolution showed the presence of inclusions (most likely of pyroxene) in the plagioclase. Despite the relatively small spread in the  $^{26}\text{Al}/^{27}\text{Al}$  ratios, the mineral separates and bulk sample of Sahara 99555 define a good isochron corresponding to a  $^{26}\text{Al}/^{27}\text{Al}$  ratio of  $(5.8 \pm 1.9) \times 10^{-7}$ , confirming the evidence for the former presence of live  $^{26}\text{Al}$  in this meteorite at the time of its formation. This value is somewhat higher (outside of 95% confidence limits) than the  $^{26}\text{Al}/^{27}\text{Al}$  ratio of  $(2.3 \pm 0.8) \times 10^{-7}$  determined for the D'Orbigny and Sahara 99555 angrites using TIMS [8]. Assuming the canonical initial  $^{26}\text{Al}/^{27}\text{Al}$  ratio of  $\sim 5 \times 10^{-5}$  at the time of CAI formation at  $4567.2 \pm 0.6$  Ma [19], we calculate an Al-Mg age of  $4562.6^{+0.3}_{-0.4}$  Ma for Sahara 99555.

As noted earlier, evidence for the former presence of live  $^{53}\text{Mn}$  was recently reported in Sahara 99555 [8]. In that study it was shown that mineral separates and a bulk sample of the D'Orbigny angrite defined a  $^{53}\text{Mn}/^{55}\text{Mn}$  isochron corresponding to a  $^{53}\text{Mn}/^{55}\text{Mn}$  ratio of  $(2.83 \pm 0.25) \times 10^{-6}$ . In the case of Sahara 99555, only pyroxenes and a bulk sample were analyzed (since olivine was too weathered). Although these had a relatively limited spread in  $^{55}\text{Mn}/^{52}\text{Cr}$  ratios, the data for Sahara 99555 were consistent with that for D'Orbigny. As such, assuming a  $^{53}\text{Mn}/^{55}\text{Mn}$  ratio of  $(2.83 \pm 0.25) \times 10^{-6}$  in Sahara 99555 at the time of its formation, we estimate a Mn-Cr age for this angrite of  $4562.2 \pm 0.7$  Ma relative to the LEW86010 angrite (which has a  $^{53}\text{Mn}/^{55}\text{Mn}$  ratio of  $(1.25 \pm 0.07) \times 10^{-6}$  [20] at  $4557.8 \pm 0.5$  [10]). This Mn-Cr age is in excellent agreement with the Al-Mg age estimated here for this angrite.

In summary, the results of our investigation of  $^{26}\text{Al}$ - $^{26}\text{Mg}$  systematics in Sahara 99555 support concordance of the Al-Mg and Mn-Cr chronometers and indicate that the Sahara 99555 and D'Orbigny angrites are older than the LEW 86010 angrite. However, preliminary results of a U-Pb investigation of D'Orbigny indicated that its absolute age (and by inference, that of Sahara 99555) is the same, within errors, as that of LEW 86010. The reason for this discrepancy is not evident and further U-Pb work on the more recently

recovered angrites will be required to address this issue.

**References:** [1] MacPherson G. et al. (1995) *Meteoritics*, 30, 365; and references therein. [2] Zinner E. and Göpel C. (2002) *MAPS*, 37, 1001. [3] Bizzarro M. et al. (2004) *Nature*, 431, 275. [4] Urey H. C. (1955) *PNAS*, 41, 127. [5] Kunihiro T. et al. (2004) *GCA*, 68, 2947. [6] Srinivasan G. et al. (1999) *Science*, 284, 1348. [7] Srinivasan G. (2002) *MAPS* 37, A135. [8] Nyquist L. E. et al. (2003) *LPS XXXIV*, #1388. [9] Wadhwa M. et al. (2004) *LPS XXXV*, #1843. [10] Lugmair G. W. and Galer S. J. G. (1992) *GCA*, 56, 1673. [11] Jagoutz et al. (2003) *MAPS*, 38, Suppl., #5148. [12] Crozaz G. and Pellas P. (1984) *EPSL*, 71, 195. [13] Nehru C. E. (1983) *PLPSC 14<sup>th</sup>*, *JGR* 88, Suppl., B237. [14] Wadhwa M. et al. (1998) *LPS XXIX*, #1480. [15] Glavin D. P. et al. (2004) *MAPS*, 39, 693. [16] Catanzaro et al. (1966) *J. Res. Natl. Res. Stand.*, 70A, 453. [17] Galy A. et al. (2003) *JAAS*, 18, 1352. [18] Bizzarro M. and Baker J. (2004) *GCA*, in press. [19] Amelin Y. et al. (2002) *Science*, 297, 1678. [20] Lugmair G. W. and Shukolyukov A. (1998) *GCA*, 62, 2863.

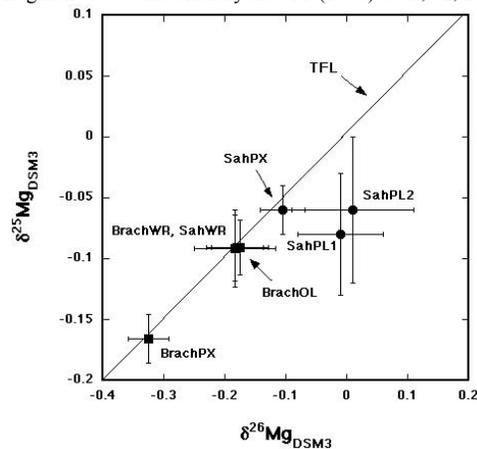


Figure 1. Mg isotopic compositions of pyroxene (SahPX) and plagioclase (SahPL1 and SahPL2) and a bulk sample (SahWR) of Sahara 99555 and pyroxene (BrachPX) and olivine (BrachOL) and a bulk sample (BrachWR) of Brachina relative to DSM3. Solid line is the terrestrial fractionation line (TFL). Errors are  $2\sigma_{\text{mean}}$ .

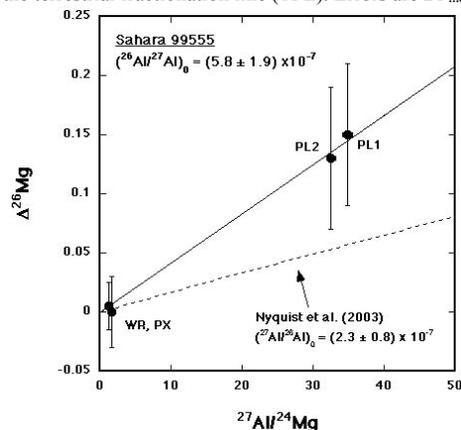


Figure 2. Al-Mg systematics in a pyroxene (PX), two plagioclase (PL1 and PL2), and a bulk sample (WR) of Sahara 99555. The Al-Mg isochron from [8] is shown as the dashed line for comparison.