^{147,146}Sm-^{143,142}Nd AND ^{87}Rb-^{87}Sr SYSTEMATICS OF THE ANGRITES NORTHWEST AFRICA 4590, NORTHWEST AFRICA 4801, AND D'ORBIGNY. M. E. Sanborn[1], R. W. Carlson[2], and M. Wadhwa[1] [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 (Email: Matthew.Sanborn@asu.edu), [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Introduction: Angrites are a small group of basaltic achondrites that are distinguished by unique geochemical characteristics and ancient crystallization ages [1]. While still relatively rare, the number of identified angrites has increased significantly in the past several years. Chronological studies of these newly recovered angrites have the potential to provide unique insights into their petrogenesis on the angrite parent body (APB). Here, we present the initial results of an investigation of Sm-Nd and Rb-Sr isotope systematics of the angrites NWA 4590, NWA 4801, and D'Orbigny. Northwest Africa (NWA) 4590 and NWA 4801 are two recently recovered coarse-grained angrites comprised primarily of Al, Ti-diopside, pure anorthite, olivine (with kirschteinite present in NWA 4590), and accessory phases such as merrillite and troilite [2,3]. In contrast, D'Orbigny is a fine-grained angrite with a quenched texture, and is comprised primarily of Al, Ti-diopside, anorthite, olivine, kirschteinite, and accessory phases such as spinel, Fe-sulfide, and phosphates [4].

The ancient crystallization ages of angrites make them particularly suited for investigating coupled ^{147,146}Sm-^{143,142}Nd systematics. Previous studies of their Sm-Nd systematics have been limited to the coarse-grained angrites LEW 86010 and Angra dos Reis [5,6] and a preliminary investigation of D'Orbigny [7]. Understanding the Sm-Nd systematics of the more recently recovered angrites can provide additional constraints on the initial Solar System ^{146}Sm/^{144}Sm ratio as well as the timing of silicate differentiation on the APB. Furthermore, the extremely volatile-depleted nature of these achondrites make them suitable for Rb-Sr investigations to determine the initial Sr isotopic composition, and hence the timing of volatile-loss, from their parent asteroid. Both the Sm-Nd and the Rb-Sr systematics can additionally provide constraints on the timing of silicate differentiation on the APB.

Analytical Methods: Mineral separates were prepared in the Isotope Cosmochemistry and Geochronology Laboratory at Arizona State University. Interior chips (~1 g) of each of the three angrites were crushed and a small fragment of each (~50 mg) was reserved as a whole-rock sample, while the remainder was processed in a Frantz magnetic separator to prepare mineral separates. These mineral separates were then further purified by handpicking.

Sample dissolution and column chemistry was completed at the Carnegie Institution of Washington (CIW). All samples, with the exception of the phosphate and whole-rock, were leached in 2.5N HCl for approximately 30 minutes (10 minutes for the olivine). Leaching of the whole-rock samples was avoided to prevent dissolution of phosphate, which is the main rare earth element carrier. All separates were spiked for Sm/Nd and Rb/Sr ratio measurements. Pyroxene, plagioclase and whole-rock samples were dissolved using a 3:1 mixture of HF-HNO_3, while phosphate and olivine were dissolved using a 6N HCl solution. Isotopic measurements of Nd, Sm, and Sr were conducted on a Thermo Triton thermal ionization mass spectrometer. Rb concentrations were measured using a Nu Instruments multicollector inductively coupled plasma mass spectrometer at CIW. To correct for the effects of neutron capture due to cosmic ray exposure, deficits in the ^{149}Sm/^{152}Sm ratio were monitored in the whole-rock samples of each of the three angrites analyzed here.

Results and Discussion: *NWA 4590 Sm-Nd Systematics.* The ^{147}Sm-^{143}Nd isochron is defined by four data points (whole-rock, phosphate, pyroxene, and olivine/kirschteinite); the plagioclase data point does not fall on this isochron. The slope of the regression line through these four data points yields an age of 4568±27 Ma (2σ error, MSWD=6.6) with an initial ^{143}Nd/^{144}Nd ratio of 0.506682±0.000052. This ^{147}Sm-^{143}Nd age is concordant with the previously reported Pb-Pb age of this angrite [8]. From the ^{147}Sm-^{143}Nd isochron, we calculate a present day ^{143}Nd/^{144}Nd relative to CHUR, i.e., $\varepsilon^{143}Nd_{CHUR}$ = -0.08±0.49 at a chondritic Sm/Nd ratio (assuming the modern average chondrite values for CHUR [9]).

As with the ^{147}Sm-^{143}Nd system, a ^{146}Sm-^{142}Nd isochron is defined by the whole-rock, phosphate, pyroxene, and olivine/kirschteinite data points. The slope of the regression line yields a ^{146}Sm/^{144}Sm ratio of 0.00745±0.00021 (MSWD=0.50) and an initial ε^{142}Nd = -2.75±0.09 (relative to terrestrial standard value). This corresponds to a present day value for ε^{142}Nd = -0.13±0.03 at a chondritic Sm/Nd ratio. Using the previously reported Pb-Pb age of NWA 4590 [8], the Solar System initial ^{146}Sm/^{144}Sm ratio (i.e., at 4568 Ma [10]) would extrapolate to 0.0079±0.0002.

NWA 4801 Sm-Nd Systematics. The whole-rock, phosphate, plagioclase, and pyroxene data points define the ^{147}Sm-^{143}Nd isochron of NWA 4801. The olivine separate lies slightly off this isochron. The slope of the ^{147}Sm-^{143}Nd isochron (Fig. 1) yields an age of 4556±82 Ma (MSWD=4.4) with an initial ^{143}Nd/^{144}Nd ratio of 0.50669±0.00010. This corresponds to a present day $\varepsilon^{143}Nd_{CHUR}$ of -0.17±0.51 at a chondritic

Sm/Nd ratio. Although the uncertainty on the ^{147}Sm-^{143}Nd age of NWA 4801 is relatively large, it is consistent with the Pb-Pb age for this angrite [8]. These ^{147}Sm-^{143}Nd systematics are, within the errors, identical to those obtained for NWA 4590.

The slope of the regression line of the ^{146}Sm-^{142}Nd isochron (Fig. 2) yields a ^{146}Sm/^{144}Sm of 0.00846±0.00075 (MSWD=1.7), which is only marginally higher than that obtained for NWA 4590. This extrapolates to an initial Solar System ^{146}Sm/^{144}Sm of 0.0090±0.0007 using the previously reported Pb-Pb age for this angrite [8]. The initial ε^{142}Nd= -3.26±0.28, which corresponds to a present day ε^{142}Nd= -0.26±0.04 at chondritic Sm/Nd.

D'Orbigny Sm-Nd Systematics. Three points define the ^{147}Sm-^{143}Nd isochron: whole-rock, plagioclase, and pyroxene. As with NWA 4801, the olivine data point lies off of the isochron. The slope of the ^{147}Sm-^{143}Nd isochron yields an age of 4507±89 Ma (MSWD = 13) with an initial ^{143}Nd/^{144}Nd ratio of 0.50677±0.00006 (present day $\varepsilon^{143}Nd_{CHUR}$ = 0.20±0.18).

The slope of the regression line of the ^{146}Sm-^{142}Nd isochron yields a ^{146}Sm/^{144}Sm ratio of 0.00618±0.0010 (MSWD=0.34) with an initial ε^{142}Nd= -2.32±0.4 (present day ε^{142}Nd = -0.14±0.05 at chondritic Sm/Nd). This ^{146}Sm/^{144}Sm ratio is significantly lower than those obtained for NWA 4590 and NWA 4801. This would extrapolate to an initial Solar System ratio of 0.0093±0.0010, similar to that derived from NWA 4801, if the relatively young ^{147}Sm-^{143}Nd age of 4507 Ma is used (instead of its ancient Pb-Pb age [11]). The ^{147}Sm-^{143}Nd age obtained here for D'Orbigny is not in agreement with the previously reported age of 3.08± 0.05 Ga obtained from a plagioclase-pyroxene tie line [7]. As such, the results of this study coupled with the previously reported data [7] suggest a significant disturbance of the Sm-Nd systematics in D'Orbigny. The process(es) which caused the disturbance of the Sm-Nd system in D'Orbigny, apparently did not cause significant disturbances in other isotopic systems (e.g., Pb-Pb, Al-Mg) [11, 12].

Rb-Sr Systematics. For plagioclase separates, using the measured ^{87}Sr/^{86}Sr ratios along with the associated ^{87}Rb/^{86}Sr ratio, and assuming a model age of 4.56 Ga, model initial ^{87}Sr/^{86}Sr ratios of 0.698973±0.000005, 0.698976±0.000005 and 0.698986±0.000005 are calculated for NWA 4590, NWA 4801, and D'Orbigny, respectively. The values for NWA 4801 and D'Orbigny are, within errors, identical to those reported previously [13]. Additional Sr isotopic measurements of whole-rock samples and other mineral separates are currently in the process of being completed.

References: [1] Mittlefehldt D. et al (1998) *Rev. Mineralogy 36, Planetary Materials,* Chapter 4, pp. 195. [2] Kuehner S. M. and Irving A. J. (2007) *LPS XXXVIII*, Abstract #1522. [3] Irving A. J. and Kuehner S. M. (2007) *Workshop on Chronology of Meteorites*, Abstract #4050. [4] Mittlefehldt D. et al. (2002) *MAPS, 37*, 345-369. [5] Lugmair G. W. and Galer S. J. G. (1992) *GCA, 56,* 1673-1694. [6] Nyquist L. E. et al. (1994) *Meteoritics, 29*, 872-885. [7] Tonui E. K. et al. (2003) *LPS XXXIV,* Abstract #1812. [8] Amelin Y. and Irving A. J. (2007) *Workshop on Chronology of Meteorites*, Abstract #4061. [9] Bouvier A. et al. (2008) *EPSL, 273,* 48-57. [10] Bouvier A. and Wadhwa M. (2010) *Nature Geoscience, 3*, 637-641. [11] Amelin Y. (2008) *GCA, 72,* 221-232. [12] Spivak-Birndorf L. et al. (2009) *GCA, 73,* 5202-5211. [13] Hans U. et al. (2010) *LPS XLI*, Abstract #2680.

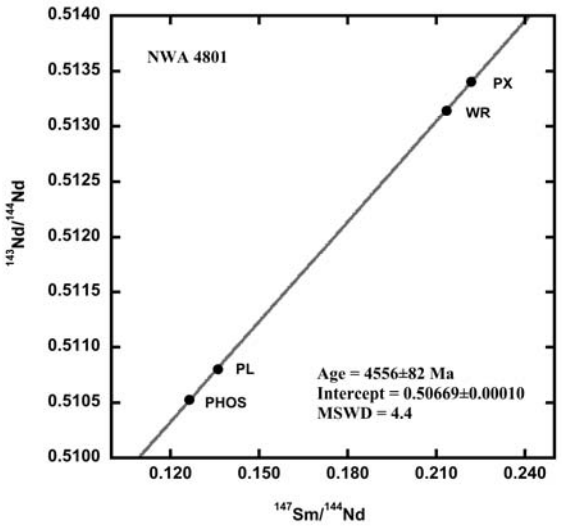

Figure 1. ^{147}Sm-^{143}Nd isochron for NWA 4801. (WR = whole-rock, Phos = phosphate, PL = plagioclase, PX = pyroxene).

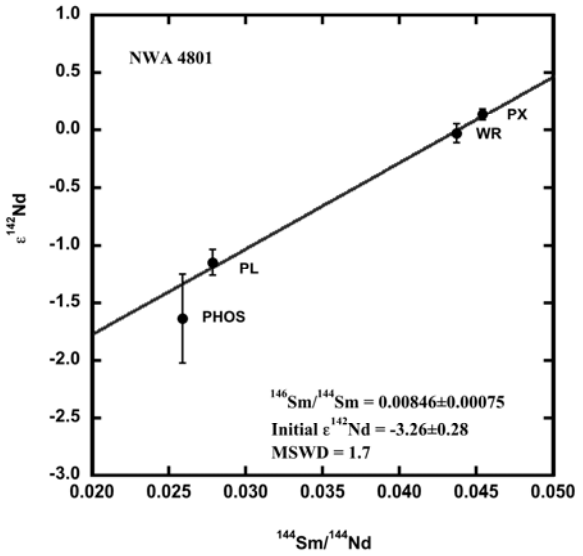

Figure 2. ^{146}Sm-^{142}Nd isochron for NWA 4801. Sample labels are identical to those in Fig. 1.