THE CHRONOLOGY OF ACCRETION AND VOLATILE DEPLETION OF DIFFERENTIATED PROTOPLANETS INFERRED FROM RB-SR SYSTEMATICS OF ANGRITES. U. Hans[1], T. Kleine[1], B. Bourdon[1]. [1]Institute for Isotope Geology and Mineral Resources, ETH Zürich, 8092 Zürich, Switzerland (ulrik.hans@erdw.ethz.ch)

Introduction: Many meteorite parent bodies as well as the terrestrial planets are characterized by a depletion in moderately volatile elements compared to CI chondrites and the solar nebula. Determining the timing of this depletion is key for constraining the nature of the depletion process and such time constraints can be obtained from the ^{87}Rb-^{87}Sr systematics of meteorites and some of their components. Volatile depletion resulted in a fractionation of volatile Rb from refractory Sr, such that the initial ^{87}Sr/^{86}Sr of a volatile-depleted planetesimals can be used to estimate the time at which this planetesimal separated from the solar nebula (or any other source reservoir with known Sr isotope evolution).

Among the planetesimals that are sampled by meteorites, the angrite parent body has the most extreme depletion in volatile elements. The ^{87}Rb-^{87}Sr systematics of angrites LEW 86010 and Angra dos Reis (AdoR) have been used previously to determine the timescale of volatile depletion [1,2] but these samples formed ~10 Myr after CAIs and thus may not represent the initial ^{87}Sr/^{86}Sr of their parent body. We developed improved techniques for precise Sr isotope measurements and present high-precision Sr isotope data for plagioclase separates from several angrites. These data are used to better determine the timing of volatile loss of the angrite parent body.

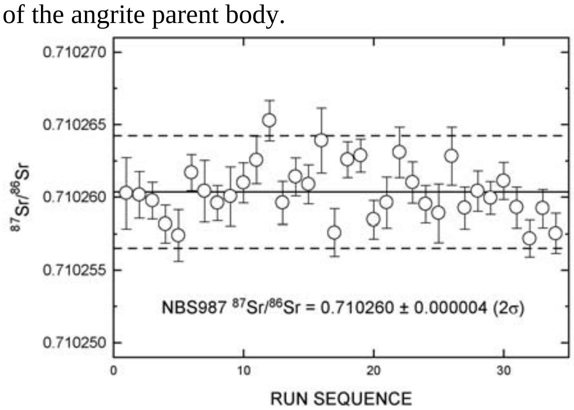

Figure 1: Measured ^{87}Sr/^{86}Sr for NBS 987over the past 9 months. The external reproducibility is ±5 ppm (2σ)

Analytical techniques: Pieces of angrites were gently crushed in an agate mortar and plagioclase was separated by handpicking. Separates were washed by ultrasonication in ethanol and then weighted into Savillex beakers. Then they were washed in cold 2 M HCl and ultrasonicated in 1 M HCl for ten minutes. The leachate was decanted and the residue washed several times in Milli-Q water. The residues were then dissolved in HF-HNO_3 overnight, dried down and re-dissolved in 6 M HCl. Complete dissolution was achieved at this stage and aliqots were taken for Rb and Sr concentration measurements by isotope dilution. After spiking, all aliquots including the unspiked aliquot were dried and Rb and Sr were purified from the sample matrix using standard cation exchange techniques. High precision Sr isotope measurements were performed in multi-dynamic mode using the Thermo-Finnigan Triton thermal ionization mass spectrometer at ETH Zurich. All runs were normalized to a ^{86}Sr/^{88}Sr of 0.1194 and measured with ~20 V on ^{88}Sr. For each run, 600 ratios were obtained, resulting in within-run precisions of ± 2-4 ppm for the ^{87}Sr/^{86}Sr ratio. The mean ^{87}Sr/^{86}Sr acquired for NBS987 over the last 9 months is 0.71260 ± 0.000004 (2 s.d.) (Fig. 1). Thus, the precision of our measurements is a factor of 4-5 better than those obtained using older generations of TIMS and potentially allows the timescale of volatile depletion to be defined much more precisely. Rubidium measurements were performed on a Nu Plasma MC-ICPMS at ETH Zurich using Zr for external mass bias correction. The Sr isotope dilution measurements were performed using TIMS.

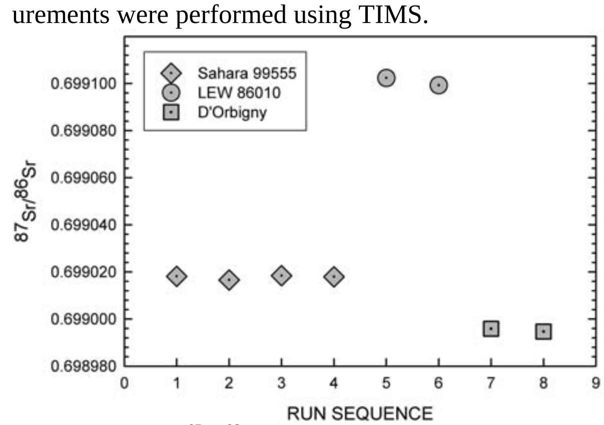

Figure 2: Measured ^{87}Sr/^{86}Sr for plagioclase separates from angrites. Uncertainties are smaller than the symbol size.

Results: Our new Rb-Sr data are summarized in Fig. 2 and 3. The new data obtained for a LEW 86010 plagioclase separate plot within the field of previously reported Rb-Sr compositions of several LEW 86010 fractions [1,2] but have slightly higher ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr ratios compared to some of the earlier reported plagioclase data (Fig. 3). A plagioclase separate from Sahara 99555 has ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr ratios similar to the least radiogenic LEW 86010 separates but has a significantly higher ^{87}Sr/^{86}Sr compared to the D'Orbigny plagioclase analysed for this study. The latter is indistinguishable from the Rb-Sr composition reported previously for AdoR [1].

Discussion: *Rb-Sr systematics of angrites*. It was noted earlier that the Rb-Sr system in LEW 86010 is disturbed by weathering and terrestrial contamination, and that no meaningful Rb-Sr isochron could be obtained [1,2]. The relatively high $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios obtained here for a plagioclase separate corrobate this interpretation and probably reflect contamination with terrestrial Rb and Sr. A similar argument can be made for the Sahara 99555 plagioclase separate, which is similar to some of the LEW 86010 separates but has a higher $^{87}Sr/^{86}Sr$ compared to AdoR and D'Orbigny plagioclase. Given that Sahara 99555 and D'Orbigny are chemically similar and have identical crystallization ages, this is unlikely to be correct and probably reflects contamination with terrestrial Sr. This suggests that our washing procedure has not entirely removed the contamination and additional analyses on more strongly leached separates will allow us to better evaluate the extent of terrestrial contamination. The $^{87}Sr/^{86}Sr$ for Sahara 99555 is therefore not considered further in the discussion below.

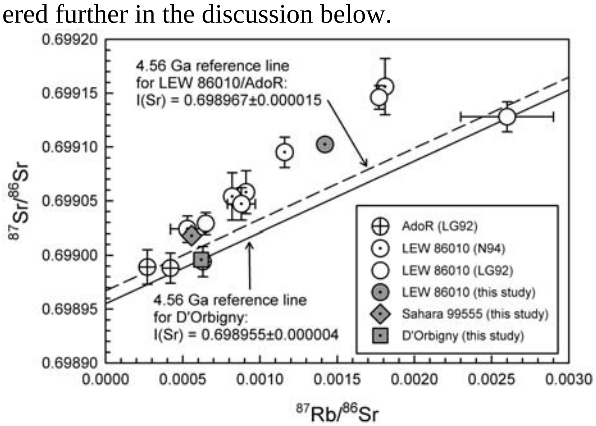

Figure 3: Rb-Sr data for angrites obtained for the present study compared to previously reported data. LG92 = [1]; N94 = [2].

The $^{87}Sr/^{86}Sr$ ratio of D'Orbigny plagioclase is among the lowest yet measured for angrites and provides the currently most precise estimate for the initial $^{87}Sr/^{86}Sr$ of the angrite parent body of 0.698955±0.000004 (Fig. 2). This value is in excellent agreement with the estimate based on AdoR and LEW 86010 of 0.698967 ± 0.000015 [1,2].

Chronology of volatile depletion. Fig. 4 illustrates how the initial $^{87}Sr/^{86}Sr$ ratios for D'Orbigny and LEW 86010 can be used to estimate the timing at which the angrite parent body separated from the high $^{87}Rb/^{86}Sr$~1.5 of the solar nebula. D'Orbigny and LEW 86010/AdoR have crystallization ages of ~4 and ~10 Myr after CAI formation and their initial $^{87}Sr/^{86}Sr$ ratios thus provide the Sr isotope composition of the angrite parent body at ~4 and ~10 Myr after CAI formation (assuming that both angrites sample the mantle of the their parent body). This allows estimating the Sr isotope evolution of the angrite parent body and calculation of the time at which the solar nebula had reached the initial $^{87}Sr/^{86}Sr$ of the angrite parent body. This time corresponds to the time of volatile depletion of the angrite parent body, provided that its Sr isotope evolution can be approximated by such a two-stage model.

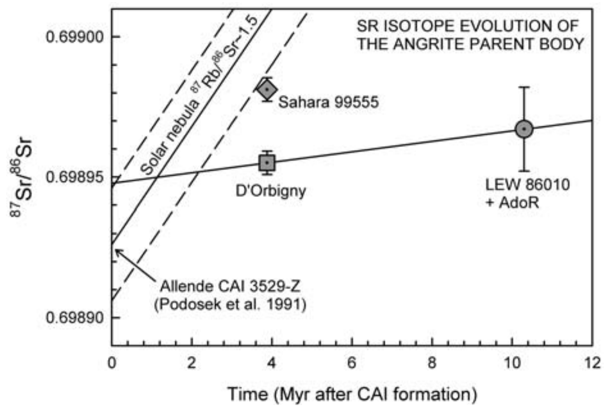

Figure 4: Sr isotope evolution diagram for angrites. The initial $^{87}Sr/^{86}Sr$ of CAIs is from Allende CAI 3529-Z, which has been argued to best represent the initial $^{87}Sr/^{86}Sr$ of the solar system [3]. The initial $^{87}Sr/^{86}Sr$ of LEW 86010/AdoR is from [1] and that of D'Orbigny from Fig. 3.

Fig. 4 reveals that in this model Rb loss from the angrite parent body must have occurred well within the first ~2 Myr after CAI formation. Fig. 3 further illustrates that the uncertainty on this age estimate is largely caused by the uncertainty in the initial $^{87}Sr/^{86}Sr$ of CAIs, such that once this value is more precisely defined, ages of higher precision can be obtained. Furthermore, the Rb/Sr of the solar nebula is not precisely defined and an additional source of error.

It may also be conceivable that the Sr isotope evolution of the angrite parent body was initially characterized by a $^{87}Rb/^{86}Sr$ ratio lower than that of the solar nebula. For instance, CI chondrites have a $^{87}Rb/^{86}Sr$ of 0.92 and in such an environment ~4 Myr are required to evolve from the initial $^{87}Sr/^{86}Sr$ of CAIs to the initial value of the angrite parent body. Although such a scenario cannot be excluded based on Rb-Sr constraints alone, such a late volatile depletion event is more difficult to reconcile with the Hf-W evidence for accretion and differentiation of the angrite parent body within the first ~2-3 Myr after CAI formation [4]. Thus, the combination of Rb-Sr and Hf-W constraints seem to favor a scenario in which volatile loss, accretion, differentiation of the angrite parent body occurred in a narrow time interval within the first ~2 Myr of the solar system.

References: [1] Lugmair and Galer (1992) *GCA 56*, 1673–1694. [2] Nyquist et al. (1994) *Meteoritics 29*, 872–885. [3] Podosek et al. (1991) *GCA 55*, 1083–1110. [4] Kleine et al. (2009), this volume.