RB-SR CHRONOLOGY OF VOLATILE DEPLETION OF THE ANGRITE AND EUCRITE PARENT BODIES. U. Hans1, T. Kleine2, B. Bourdon1. 1Institute of Isotope Geochemistry and Mineral Resources, ETH Zürich, 8092 Zürich, Switzerland; 2Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster. (ulrik.hans@erdw.ethz.ch)

Introduction: Relative to CI chondrites most planetary bodies in the inner solar system are depleted in volatile elements. Determining the timing of this depletion is key for constraining the nature of the depletion process and such time constraints can be obtained using the decay of moderately volatile $^{87}\text{Rb}$ to more refractory $^{87}\text{Sr}$. The $^{87}\text{Rb} - ^{87}\text{Sr}$ systematics of angrites [LEW 86010 and Angra dos Reis (AdoR)] and eucrites [1, 2] have been used to argue that their parent bodies accreted and lost their volatiles late, more than 2-3 Ma after solar system formation [3]. This timescale however is inconsistent with Al-Mg and Hf-W evidence for rapid accretion of differentiated protoplanets [4, 5]. The reasons for this disparity in ages are unclear and to address this important issue we developed improved techniques for precise Rb-Sr measurements and present here a comprehensive set of high-precision Rb-Sr isotope data for eucrites and plagioclase separates from several angrites.

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 eucrite whole-rock powders were not leached with HCl. The angrite separates and eucrite whole-rock powders were then dissolved in HF-HNO$_3$ over night, dried down and redisolved in 6 M HCl. Complete dissolution was achieved at this stage and aliquots 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 $^{88}\text{Sr}$ of 0.1194 and measured with -20 V on $^{88}\text{Sr}$. For each run, 600 ratios were obtained, resulting in within-run precisions of $\pm$ 2-4 ppm for the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio. The mean $^{87}\text{Sr}/^{86}\text{Sr}$ acquired for NBS987 is 0.71250 $\pm$ 0.000002 (2 s.d.). Thus, the external precision of our measurements is a factor of 4-5 better than those obtained using older generations of TIMS and potentially allow 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.

Results: Our new Rb-Sr data are summarized in Fig. 2 and 3. The $^{87}\text{Sr}/^{86}\text{Sr}$ obtained for AdoR is indistinguishable from but a factor of 4-5 more precise than values obtained in a previous study [1]. Its $^{87}\text{Rb}/^{86}\text{Sr}$ ratio however is much higher than those reported previously (Fig. 2). Likewise, two plagioclase separates from different pieces of D’Orbigny have identical $^{87}\text{Sr}/^{86}\text{Sr}$ ratios but different $^{87}\text{Rb}/^{86}\text{Sr}$ ratios. Remarkably, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the two D’Orbigny separates are indistinguishable from the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios reported for AdoR, in spite of differences in $^{87}\text{Rb}/^{86}\text{Sr}$. A plagioclase separate from NWA 4801 has a slightly higher $^{87}\text{Sr}/^{86}\text{Sr}$ than D’Orbigny and AdoR but plots along the 4.56 Ga reference line drawn through one of the D’Orbigny data points.

Whole-rock samples of several basaltic and cumulates eucrite obtained for this study agree with previously published data for eucrites but are also a factor of 4-5 more precise than the earlier results. Basaltic and cumulate eucrites plot on a single isochron, whose initial $^{87}\text{Sr}/^{86}\text{Sr}$ is 0.698980 $\pm$ 0.000027 (Fig. 3).

Discussion: A striking observation from our new Sr isotopic data for angrites is that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for most samples are indistinguishable although their $^{87}\text{Rb}/^{86}\text{Sr}$ ratios vary. This pattern seems to reflect a recent addition of Rb to the samples, such that using their $^{87}\text{Rb}/^{86}\text{Sr}$ ratios to correct for $^{87}\text{Rb}$ decay results...
in spurious initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Instead, the measured $^{87}\text{Sr}/^{86}\text{Sr}$ seems to more accurately reflect the true initial $^{87}\text{Sr}/^{86}\text{Sr}$ of these angrites. The $^{87}\text{Rb}/^{86}\text{Sr}$ ratio of one of the D’Orbigny plagioclase separates is among the lowest yet measured for angrites and is ~0, such that its $^{87}\text{Sr}/^{86}\text{Sr}$ provides the currently most precise estimate for the initial $^{87}\text{Sr}/^{86}\text{Sr}$ of the angrite parent body of 0.698984±0.000002 (Fig. 2). An NWA 4801 plagioclase may be too high due to the contamination with terrestrial Sr during desert weathering of NWA 4801. Alternatively, the $^{87}\text{Sr}/^{86}\text{Sr}$ of the NWA 4801 plagioclase may be too high due to the contamination with terrestrial Sr during desert weathering of NWA 4801.

The source of the Rb contamination in most angrites remains poorly constrained, as is the reason why some angrites may contain indigenous Rb while others don’t. Resolving this enigma will require additional Rb-Sr analyses of well characterized mineral separates from angrites. For the current best estimate for the initial $^{87}\text{Sr}/^{86}\text{Sr}$ of the angrite parent body is 0.698984±0.000002 (see above). This value is higher than previous estimates for the initial $^{87}\text{Sr}/^{86}\text{Sr}$ of angrites [1, 2] but agrees with BABI, the initial $^{87}\text{Sr}/^{86}\text{Sr}$ of the eucrite parent body, determined in this and previous studies.

The difference between the initial $^{87}\text{Sr}/^{86}\text{Sr}$ of angrites/eucrites and CAI’s should allow determining the time at which the angrite and eucrite parent bodies separated from the high Rb/Sr solar nebula [4, 5]. Since these two parent bodies appear to have indistinguishable initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, they also have identical volatile depletion ages. Fig. 4 reveals that volatile element depletion of these two bodies occurred within the first 4 Ma of the solar system. The major source of uncertainty in this age estimate comes from uncertainties in the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of CAIs (Fig. 4). Note that in Fig. 4 the uncertainties of the two estimates for the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of CAIs of ± 0.00002 are not shown. Obviously high-precision Sr isotope analyses of CAIs are needed before a more precise Rb-Sr chronology of the angrite and eucrite parent bodies can be established. Furthermore, if our hypothesis that large parts of the Rb found in angrite plagioclase has been added recently, then this might have also been relevant for CAIs. Rb-Sr data for Allende CAIs indeed show variations in their Rb/Sr ratio while variations in $^{87}\text{Sr}/^{86}\text{Sr}$ are limited.

For instance, if it is assumed that the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of CAIs is given by their measured $^{87}\text{Sr}/^{86}\text{Sr}$, then the true $^{87}\text{Sr}/^{86}\text{Sr}$ initial of CAIs would be higher than shown in Fig. 4. In this case, volatile element depletion in angrites and eucrites would have to have occurred in the first ~2 Ma after CAI formation. Remarkably, this timescale would be consistent with the Hf-W evidence for accretion of the angrite and eucrite parent bodies within the first ~1-2 Myr of the solar system [12].