Rb-Sr systematics of ungrouped achondrites

THE AUSTRALIAN NATIONAL UNIVERSITY

Yuri Amelin, Australian National University

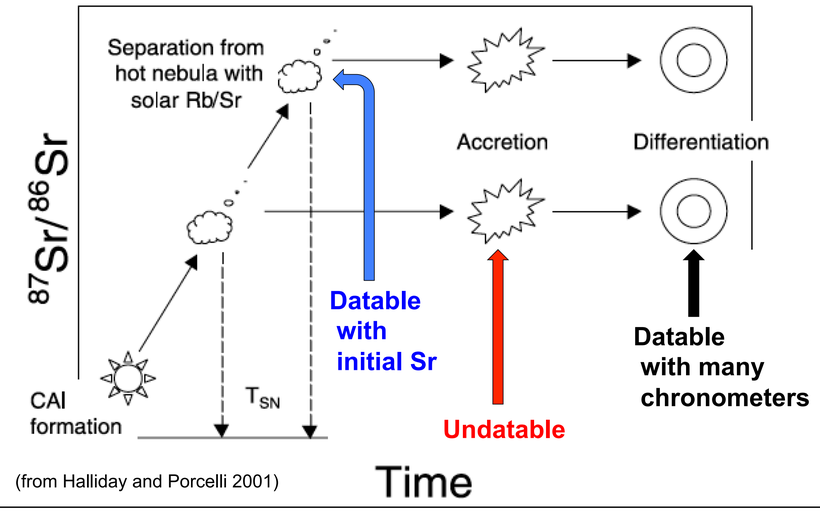
Introduction Achondrites are rocks from asteroids that underwent melting and in some cases differentiation. Several achondrites found in the recent years have unique chemical and isotopic characteristics, and do not fit in the established groups. Studies of these meteorites give a glimpse of the diversity of asteroids that formed and partially melted in different domains in the accreting protosolar nebula, at different time, from different source materials, and under different conditions.

Most achondrites are depleted in moderately volatile elements including alkaline metals, and have low Rb/Sr ratio, and hence contain only small fraction of radiogenic ^{87}Sr produced in situ. It is therefore possible to calculate their initial ^{87}Sr/^{86}Sr with small uncertainty, and apply the initial Sr chronometer to determine the time of separation of their source material from the protosolar nebula.

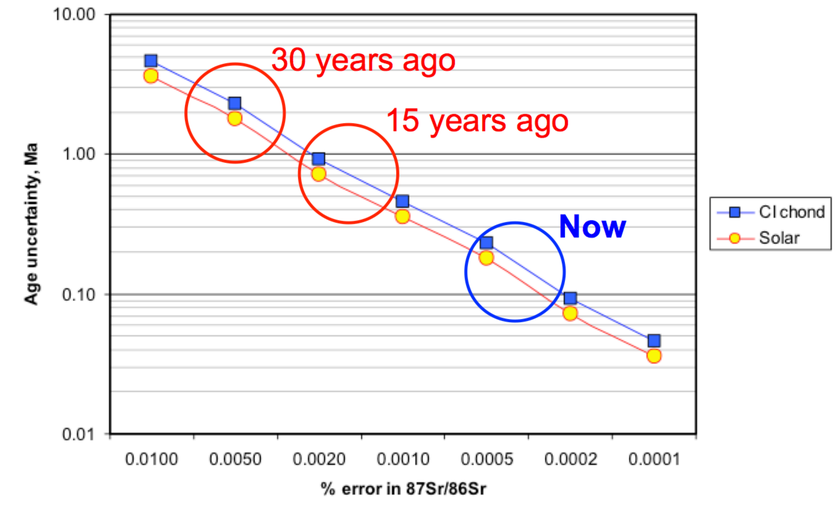
Here I present ^{87}Rb-^{87}Sr data for five ungrouped achondrites: NWA 8486, a mafic cumulate rock paired with NWA 7325, Asuka 881394, the oldest known achondrite that resembles cumulate eucrites in mineralogy but has non-HED oxygen isotope composition, and three unusual primitive achondrites NWA 6693, NWA 6704, and NWA 10132. All these meteorites have well-behaved U-Pb systems, and, with Pb-isotopic, ^{238}U/^{235}U-corrected ages between 4562-4566 Ma, are among the oldest achondrites, and thus good candidates for initial Sr dating.

Initial ^{87}Sr/^{86}Sr chronometry – is it relevant today?

The initial ^{87}Sr/^{86}Sr chronometer was introduced in the early days of cosmochemistry and cosmochronology, when extinct radionuclide chronometers were not yet developed, and precision of U-Pb dating was relatively low. Is this chronometer still relevant now? Yes, because it allows dating different events that other chronometers. With a combination of initial Sr and other chronometers, we can bracket the time of accretion.



(from Halliday and Porcelli 2001)



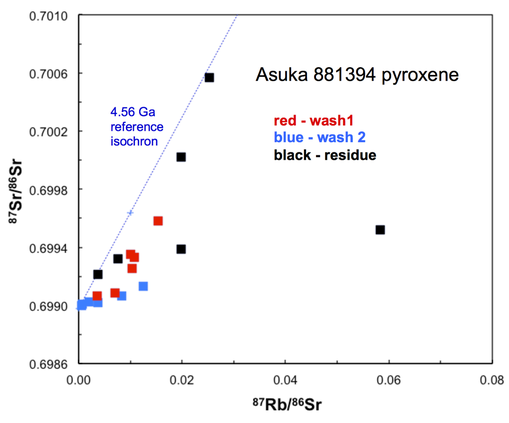
Precision enhancements in isotope ratio mass spectrometry of the last two decades allow, in principle, about an order of magnitude higher precision of the initial ^{87}Sr/^{86}Sr dates compared to the late 1960's – early 1970's when this chronometer was developed. And dramatic increase in the number of known achondrites derived from multiple parent bodies makes the initial ^{87}Sr/^{86}Sr chronometer even more useful than before.

Methods First, analyses of pyroxene fractions prepared for U-Pb dating. This part of work had a dual purpose: to determine the initial ^{87}Sr/^{86}Sr, and to evaluate the feasibility of a Rb-Sr study of achondrite minerals as a piggyback to the U-Pb dating (hence using cleaning procedures optimized for U-Pb dating), The pyroxene was hand-picked and cleaned using our standard procedures that include leaching in 0.5M HNO_3, 7M HNO_3, 6M HCl and 0.5M HF. Washes containing matrix elements including Rb and Sr were collected after Pb and U separation, and split into two aliquots: 10-40% aliquots for Rb and Sr concentration determinations with ^{85}Rb-^{84}Sr spike, and 60-90% for isotope analysis of unspiked Sr.

An additional set of mineral fractions (olivine, pyroxene, plagioclase, and whole rock) was prepared for each of NWA 6693, NWA 6704, and NWA 10132. These fractions were thoroughly cleaned by repeated ultrasonic agitation in high purity water, but were not subjected to any acid leaching. The sample solutions were aliquotted for isotope dilution and isotopic composition measurements.

Strontium was separated on the columns packed with 50 µm of Eichrom Sr-spec resin, loaded on outgassed Re filaments with TaF_5 solution, and analysed at the ANU on the Triton Plus TIMS in static mode with normalization to ^{88}Sr/^{86}Sr=8.37521, using amplifier rotation for the unspiked isotope composition runs. Analyses of the NIST SRM 987 standard during the course of this study yielded ^{87}Sr/^{86}Sr = 0.7102494 ± 0.0000028 (0.0004% 2SE, n=34) and ^{84}Sr/^{86}Sr= 0.0564905 ± 0.0000010 (0.0018% 2SE, n=34). All data are reported relative to ^{87}Sr/^{86}Sr = 0.71025 in SRM 987. Rubidium was analysed without chemical separation by loading small aliquots (ca. 0.1-1% of the total spiked aliquot) on Re filaments with silicagel, and measuring on a modified MAT 261 TIMS. The data are corrected for total procedure blanks of 2-4 pg Sr and 0.2-0.3 pg Rb measured in each session. The initial ^{87}Sr/^{86}Sr are calculated using the Pb-isotopic ages of the respective achondrites, and the ^{87}Rb decay constant of (1.3972 ± 0.0045)x10^{-11} a^{-1} recommended by the joint IUPAC-IUGS task group on isotope data in geosciences (Villa et al. 2015).

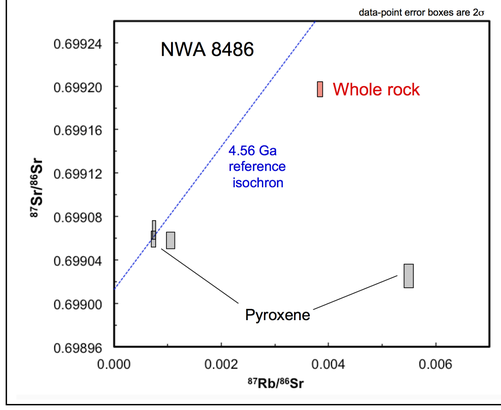
Asuka 881394 (ungrouped eucrite-like differentiated achondrite)



Pyroxenes from Asuka 881394 contain 1.8-30 ppm Sr (calculated from analyses of washes and residues). The data show presence of recently added Rb.

The measured and decay corrected data for the second washes of two Sr-rich fractions with low ^{87}Rb/^{86}Sr below 0.0007, yield the best estimate initial of 0.699984±0.000018. It is indistinguishable from the value of 0.699989±0.000014, determined by Nyquist et al. (2011) from analysis of multiple minerals from that meteorite.

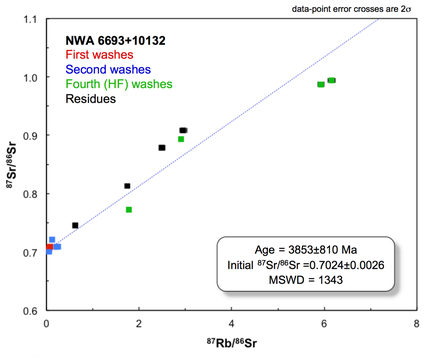
NWA 8486 (ungrouped differentiated achondrite paired with NWA 7325)

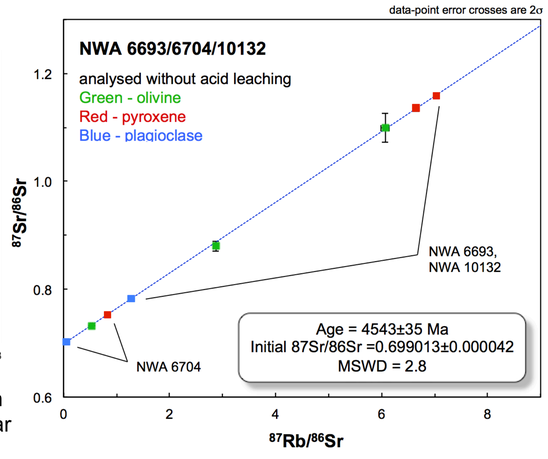


Only residues were. Four pyroxene fractions and one whole rock contain 16-20 ppm Sr. Rb concentrations are between 4.5-33 ppb. Measured ^{87}Sr/^{86}Sr are between 0.69903 and 0.69920. The two fractions with the lowest ^{87}Rb/^{86}Sr<0.001 yield consistent initial ^{87}Sr/^{86}Sr with the weighted average value of 0.699019±0.000013, which can be tentatively considered initial ^{87}Sr/^{86}Sr.

NWA 6693, NWA 6704, NWA 10132

(ungrouped primitive achondrites)





All minerals in these meteorites have high Rb/Sr ratios. Whole rock values are similar to those in CI chondrites.

Acid leaching severely disturbs ^{87}Rb-^{87}Sr systems in these meteorites. The data for leachates and residues are widely dispersed, while the data for mineral fractions washed with water, ethanol and acetone only form a well constrained isochron.

Discussion With current precision of Sr isotope analysis, initial ^{87}Sr/^{86}Sr of achondrites can potentially yield precision of initial Sr dates relative to the solar nebula of 1 Ma or even better. Application of the initial Sr chronometer is hampered by the presence of Rb introduced in the terrestrial environments, and by decoupling of Rb and radiogenic Sr induced by the mineral cleaning procedures. The leaching induced disturbance can be undone by data recombination, but verification by analysis of unleached fractions is desirable. The CAI reference initial ^{87}Sr/^{86}Sr needs improvement by additional analysis of best preserved CAIs with negligible Rb from several CV chondrites.