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^{39}Ar-^{40}Ar AGES OF FOUR UREILITES; D. D. Bogard[1] and D. H. Garrison[2]

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Abstract. Ureilites Novo Urei, Haverö, and Kenna show strong evidence of one or more ^{40}Ar degassing events in the time period of 3.3-4.1 Ga ago. These ages may be compared to current interpretations of ureilite chronology. These include the suggestion of metasomatic activity on the parent body 3.7 Ga ago that reset some Sm-Nd ages and the suggestion that ureilites have experienced terrestrial contamination of several trace elements (including Pb and LREE), which makes suspect ages younger than ~4.5 Ga [1, 2].

The detailed isotope chronology of ureilites, critical in deciphering their enigmatic history, has proved elusive. Takahashi and Masuda [3] reported a Rb-Sr isochron age of 4.01 ± 0.06 Ga for the MET78008 ureilite. Goodrich et al. [1] reported that three ureilites defined a Sm-Nd isochron age of 3.74 ± 0.02 Ga, which was interpreted as the probable time of metasomatic activity and introduction of additional LREE and other components. A few other ureilites not showing enhanced LREE defined Sm-Nd model ages of 4.55 Ga. Sr suggested correlation with LREE enrichments and was sufficiently radiogenic to suggest a later introduction. In a U-Th-Pb study of Goalpara by Torigoye et al. [2] most analyses plotted above a 4.5 Ga isochron, which was interpreted as indicating significant terrestrial Pb contamination. They found LREE enrichments only in the acid leaches of the carbon- and metal-rich phases and suggested that a portion of various incompatible elements, including Pb and the LREE, may be terrestrial contamination. This study suggests that the 3.74 Ga isochron is a mixing line and that the formation age of ureilites is ~4.55 Ga..

Because the K-Ar chronometer can be sensitive to metamorphic events, we made ^{39}Ar-^{40}Ar determinations on bulk samples (0.12-0.14 g each) of four ureilites. Novo Urei and Kenna (a fall) were included in the group that suggested a Sm-Nd age of 3.74 Ga [1]; PCA86502 was included in the group that gave a Sm-Nd age of 4.55 Ga [1]. Haverö (a fall) has not been dated, but a significant LREE enrichment was reported [3]. The determined [K] for our samples ranged 1.3-20 ppm (Fig. 1); literature data for bulk ureilites range ~0.7-35 ppm [4, 5]. Nevertheless, corrections to ^{40}Ar and ^{39}Ar for system blanks were relatively small. Corrections for reactor interferences were sometimes substantial, however, especially at high extraction temperatures where the K/Ca ratio was very small. Uncertainties in blank and reactor corrections, along with uncertainties in measurements of ratios and neutron flux levels, are included in the age uncertainties.

The ^{39}Ar-^{40}Ar age spectra (rectangles, left scale) and K/Ca ratios (dashed line, right scale) as a function of cumulative ^{39}Ar release from stepwise temperature extractions for the four ureilites analyzed are shown in Fig. 1. The total age for Haverö is 4.2 Ga; five extractions degassing ~65% of the K sites indicate a quasi-plateau age of 3.0-3.5 Ga. Ages for Novo Urei generally decrease with extraction temperature, suggesting possible redistribution of ^{40}Ar; the total age of all extractions is 3.71 Ga. The total age for Kenna is 5.75 Ga, and that for PCA86502 is 5.67 Ga. The higher ages shown by the first few extractions of Haverö and PCA86502 are associated with much higher K/Ca and probably represent contamination by K and adsorbed atmospheric ^{40}Ar. The first two extractions of Kenna probably also represent adsorbed atmospheric ^{40}Ar. The increased ages at the highest extraction temperatures of all four samples are associated with very low K/Ca ratios (~10^{-4}) and K concentrations. Although these higher ages may reflect lesser degrees of degassing (e.g., the highest ages for Kenna and Novo Urei are ~4.5 Ga), they may also be due to ^{40}Ar contamination. Unusually high total gas pressures were observed at higher extraction temperatures, and these high ages may be due to enhanced ^{40}Ar furnace blanks caused by CO-CO_2 released from high temperature carbon reduction of iron oxides.

Because ^{39}Ar-^{40}Ar ages shown by low and high temperature extractions may be suspect, we examined the intermediate temperature extractions. Five extractions (5-70% ^{39}Ar release) of Haverö suggest an age of 3.30 Ga. Four extractions of Kenna (~25-80% ^{39}Ar) suggest an age of 4.1 Ga, similar to the Rb-Sr age reported for MET78008 [3]. Extractions of Novo Urei releasing >40% of the ^{39}Ar suggest an age 3.30 Ga. However, because no obvious reason exists to suspect the low temperature extractions of Novo Urei, we note that the age given by the 0-90% ^{39}Ar release is 3.7 Ga, identical to the total age. The lowest ages shown by two extractions of PCA86502 are 4.5-4.6 Ga, identical to the PCA86502 Sm-Nd age [1] and the maximum Ar ages shown by Kenna and Novo Urei. Although interpretation of these spectra is obviously uncertain, we believe that the most recent times of Ar degassing can be roughly inferred. These times are ~3.3 Ga for Haverö, 3.3-3.7 Ga for Novo Urei, and ~4.1 Ga for Kenna, for which Ar degassing may not have been complete.

We examined the possibility that some of the excess ^{40}Ar might be associated with the large concentrations of trapped Ar known to occur in the diamond/graphite phase of ureilites. A study of Haverö [6]

gave an upper limit to the trapped $^{40}Ar/^{36}Ar$ ratio of 0.0076; the predicted cosmic ratio is considerably smaller. Our Novo Urei and PCA86502 data define trapped $^{36}Ar/^{38}Ar$ ratios of 5.26 ± 0.03 and 5.32 ± 0.03, respectively, similar to the value of 5.20 ± 0.06 reported by [6]. A correlation plot of $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ for Novo Urei (Fig. 2) shows the significant range in isotopic ratios caused by the preferential release of trapped ^{36}Ar at higher temperatures compared to ^{40}Ar and ^{39}Ar. The large ($>10^3$) variations in $^{40}Ar/^{36}Ar$ ratios show that ^{40}Ar is not associated with trapped ^{36}Ar. The other three ureilites give similarly large variations in $^{40}Ar/^{36}Ar$; the lowest ratio observed was 0.013 for the 1300°C extraction (~55% ^{39}Ar release) of PCA86502. Correction for planetary ^{40}Ar assuming $^{40}Ar/^{36}Ar = 0.007$ produced no significant changes in the age spectra, even at high extraction temperatures. Thus, we conclude that planetary ^{40}Ar is a negligible component in these ureilites.

The indication of ^{39}Ar-^{40}Ar degassing ages of 3.3-4.1 Ga for three ureilites that also contain an enhanced LREE component and (excepting Haverö) produce a 3.74 Ga Sm-Nd age [1], suggests that both chronometers may have responded to the same parent body event. On the other hand, it is also possible that the Ar data reflect one or more separate events that did not strongly affect the Sm-Nd system, a situation that commonly occurs in eucrites [7]. Thus the existence of reset Ar ages does not require similarly reset Sm-Nd ages. It seems unlikely that the reset Ar ages could have been caused by terrestrial contamination of incompatible elements (including Pb and LREE), as was suggested by [2] to explain the U-Pb and Sm-Nd results. However, if terrestrial K were also introduced into these ureilites along with other trace elements, and if that K contaminant occupies similar (interstitial?) lattice sites to indigenous K in the ureilites, then it would be possible, in principle, to generate a ^{39}Ar-^{40}Ar release spectrum showing artificially young ages. Because of its relatively high [K], such a K contaminant would produce the least effect on Novo Urei, whose total ^{39}Ar-^{40}Ar age is 3.7 Ga.

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