THERMAL RESETTING OF RADIOMETRIC AGES. I: EXPERIMENTAL INVESTIGATION; L.E. Nyquist, D.D. Bogard, NASA Johnson Space Center, Houston, TX, 77058; D.H. Garrison, B.M. Bansal, H.Wiesmann, and C.-Y. Shih, Lockheed Engineering and Science Co., 2400 NASA Road 1, Houston, TX 77258.

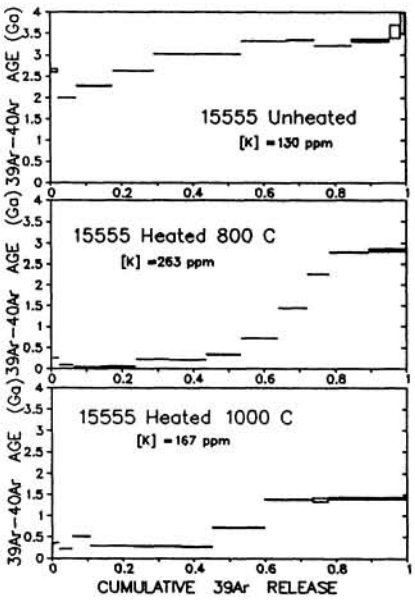

Figure 1. ^{39}Ar-^{40}Ar ages as a function of the fraction of ^{39}Ar released.

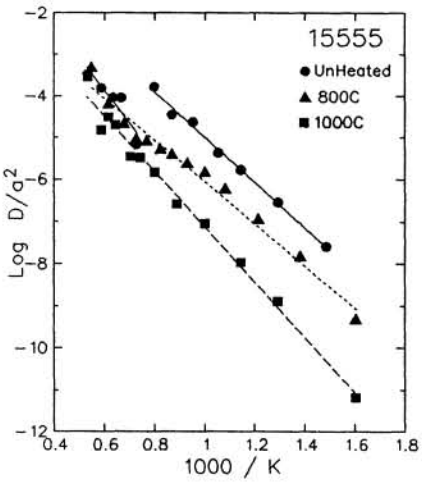

Figure 2. Arrhenius plots for the 15555 samples. Separate trends are defined for the low and high temperature phases of the unheated sample.

We have heated samples of lunar basalt 15555 to 790°C and 990°C, respectively, for 170 hours at a pressure of $<10^{-6}$ torr and compared the ^{39}Ar-^{40}Ar, ^{87}Rb-^{86}Sr, and ^{147}Sm-^{143}Nd isotopic systems to those of an unheated sample. The purpose of this experiment was to compare the relative degree of isotopic resetting of the three chronometers. A second objective was to compare age resetting in the artificially heated basalt to apparent partial resetting of ^{39}Ar-^{40}Ar, ^{87}Rb-^{87}Sr, and ^{147}Sm-^{143}Nd ages of eucrite LEW85302, which apparently was heated to >800°C by an impact on its parent body (1).

The apparent ^{39}Ar-^{40}Ar ages for an unheated sample and samples heated at 790°C and 990°C, respectively, were determined as a function of cumulative release of ^{39}Ar during stepwise degassing (Figure 1). The unheated sample shows some prior loss of radiogenic ^{40}Ar at lower extraction temperatures. The ^{39}Ar release and the K/Ca ratio (which changes by a factor of $\sim 10^4$ during gas release) as a function of temperature indicate the presence of two distinct phases. The partial loss of ^{40}Ar is associated with the lower temperature phase which contains ~55% of the K. The ^{39}Ar-^{40}Ar age for the higher temperature phase is 3.31 Ga, in good agreement with previous determinations of the ^{39}Ar-^{40}Ar age (2,3).

The samples heated at ~790°C and ~990°C show increasing loss of radiogenic ^{40}Ar compared to the unheated sample, with losses being greater for the low-temperature phase than for the high-temperature phase. Although no textural differences among the three samples are observable (G. McKay, pers. comm.), heating these samples apparently created changes either in grain sizes or in phase structure that increased the difficulty of diffusion of Ar from the low-temperature phase. This was manifested in a significant upward shift in the temperature required to degas Ar from the low-temperature phase of the 790°C and 990°C samples and by a decrease in the diffusion parameter, D/a^2, at a given temperature by an order of magnitude between the unheated sample and the 800°C sample, and again between the 800°C and 1000°C samples (Figure 2).

The presence of distinct K-bearing phases with different Ar diffusion properties and the alteration of diffusion properties during heating complicate interpretation of the degassing of radiogenic ^{40}Ar during heating. Nevertheless, we can estimate the loss of ^{40}Ar separately for the low-temperature and high-temperature phases of 15555, using ~55% cumulative release of ^{39}Ar as the approximate boundary for Ar release between these two phases. The fractional losses of ^{40}Ar for the low-temperature and high-temperature phases, respectively, relative to the unheated sample, are 97% and 88% for the 790°C sample and 95% and 78% for the 990°C sample.

The heating also disturbed both the Rb-Sr and Sm-Nd systems, as manifested by the Rb-Sr data of the sample heated to 1000°C (Figure 3). Mineral separation was according to density in order to make the processing of all three samples as equivalent as possible. Initial analyses were of plagioclase (<2.85 g/cm^3) and pyroxene (3.45-3.55 g/cm^3 and 3.55-3.7 g/cm^3, respectively) since these

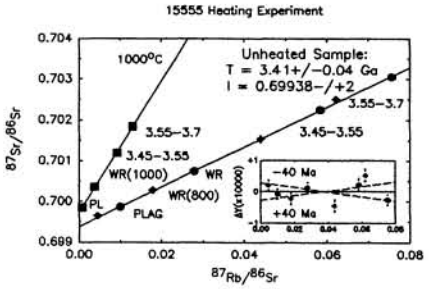

Figure 3. Rb–Sr isochron diagram. Circles: unheated sample; diamonds: 800°C sample; squares: 1000°C sample.

phases contain significant concentrations of Rb, Sr, Sm, and Nd. Longhi et al. (4) give the modal abundances of Ol, Px, Plag, opaques, and (glass+silica) as 12.1%, 52.4%, 30.4%, 2.7%, and 2.3%, respectively. We have not as yet analyzed the latter "quintessence" phase.

Rb–Sr data for the 1000°C sample yield a well-defined line of slope corresponding to an apparent age of 10.3±0.3 Ga. The Rb–Sr data of the sample heated to 800°C differs qualitatively from that of the sample heated to 1000°C in that the apparent isochron age, 3.43±0.09 Ga, is the same within uncertainty as that for the unheated sample, 3.41±0.04 Ga. These ages lie at the high end of the range of previously determined Rb–Sr ages (5–8). Whether this is due to determination of the ages reported here by data for pyroxene separates, rather than for ilmenite and/or quintessence as in the earlier studies remains to be investigated. Apparent loss of Rb from pyroxene separates has been observed in earlier studies.

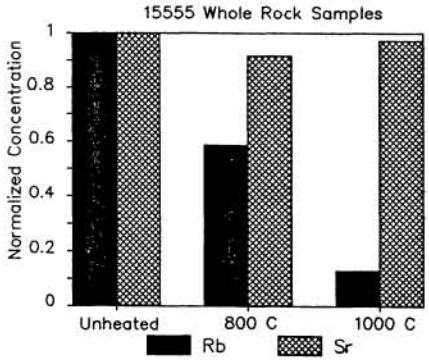

Figure 4. Concentrations of Rb and Sr in 15555 samples heated to 800°C and 1000°C, normalized to values for an unheated sample.

Comparison of Rb concentrations in samples heated to 800°C to those in unheated samples show that the actual disturbance of the Rb–Sr system is greater than appears from the isochron diagram. The Rb concentration in all separates analyzed is typically 40–50% less than for the corresponding unheated sample. Figure 4 shows the comparison for whole rock samples; similar comparisons can be made for plagioclase and pyroxene separates as well. The approximate preservation of an isochron relationship suggests that the samples heated to 800°C lost both Rb and radiogenic $^{87}Sr^{*}$ relative to values in unheated samples. We note that the "low temperature" phase observed in the Ar release contains ~55% of the total K. It is reasonable to associate the low temperature phase with "quintessence". Rb losses at 800°C are typically 40–60% for all mineral separates (cf. Figure 4) and suggests that much of the Rb loss may arise from contaminating quintessence included with the major mineral separates.

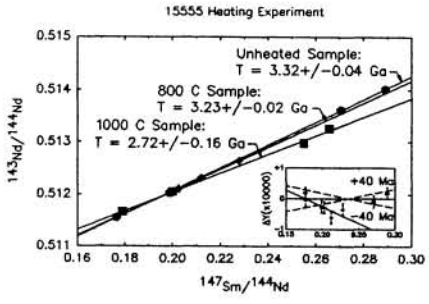

Figure 5. Sm–Nd isochron diagram. Symbols as in Figure 3.

The Sm–Nd data in Figure 5 show the "classic" pattern for isochron resetting with separate linear arrays for each sample which intersect near the data for the whole rock analyses. The internal isochron age is 3.32±0.04 Ga, in good agreement with earlier determinations of the age of 15555. Samples heated to 800°C define a slightly younger age of 3.23±0.02 Ga which appears to be resolved from that of the unheated sample. The apparent age of the sample heated to 1000°C is only 2.74±0.16 Ga and the linearity of the data array is only moderately disturbed. Apparently, preservation of a good linear array is a necessary but not sufficient criteria for the validity of an isochron age as shown by both the 800°C and 1000°C Sm–Nd data.

REFERENCES: (1) Batchelor J.D. and Sears D.W.G. [1990] LPS XXI, 54–55. (2) Alexander E.C. et al., [1972] Science 175, 417–419. (3) Podosek F.A., Huneke J.C. and Wasserburg G.W. [1972] Science, 423–425. (4) Longhi J., et al. [1972] In: The Apollo 15 Lunar Samples, 131–134. (5) Murthy V.R., et al. Science 175, 419–421. (6) Wasserburg G.J. and Papanastassiou D.A. [1971] EPSL 13, 97–104. Birck J.L., et al. [1975] EPSL 26, 29–35. (7) Chappell B.W. et al., [1972] Science 175, 415–416. (8) Papanastassiou D.A. and Wasserburg G.J. [1973] EPSL 17, 324–337.