THERMAL RESETTING OF RADIOMETRIC AGES. II: MODELING AND APPLICATIONS; 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.

The companion abstract (1) describes an experiment to compare age resetting produced in the ^{39}Ar–^{40}Ar, ^{87}Rb–^{87}Sr, and ^{147}Sm–^{143}Nd systems by heating lunar basalt 15555 in vacuum for ~1 week. This abstract quantifies the results in the context of a volume diffusion model. For Ar, this model was described by (2). For the Rb-Sr and Sm-Nd systems we use the adaptation of the model described by (3).

Table I. Elemental Loss or Exchange (F) and Diffusion Parameters α and D/a^2.

El/Min	F (800°C)	F (1000°C)	α (800°C)	α (1000°)	D/a^2 (800°C)	D/a^2 (1000°C)
Rb/plag	0.53	0.88	0.19	0.39	5.7×10^{-8}	2.6×10^{-7}
Rb/px	0.39	0.85	0.13	0.37	2.8×10^{-8}	2.2×10^{-7}
Sr/plag	-	0.30	_	0.10	-	1.6×10^{-8}
Sr/px	-	0.29	_	0.095	-	1.5×10^{-8}
Nd/plag		0.12	-	0.035	-	2.0×10^{-9}
Nd/px	0.03	0.16	-	0.05	1.2×10^{-10}	4.1×10^{-9}
Ar/Lo-T	0.97	0.95	0.55	0.50	4.9×10^{-7}	4.1×10^{-7}
Ar/Hi-T	0.88	0.78	0.40	0.32	2.6×10^{-7}	1.7×10^{-7}

The model characterizes the diffusion process via the fraction $F = 1-(C/C_o)$ lost from a volume in which the diffusing species has average concentration C after diffusive loss occurs from an initial concentration, C_o. F is expressed as a function of α, where $\alpha = [Dt/a^2]$ and D is the diffusion coefficient, t is time and a the characteristic diffusion length. As described in the companion abstract, Ar loss during stepwise heating of the basalt occurred primarily from a low temperature (Lo-T) phase containing ~55% of the K in the basalt and a high temperature phase or combination of phases (Hi-T) containing the remaining K. The fractional loss of ^{40}Ar from these two phases during heating at ~800°C and ~1000°C, respectively, are listed in Table I with the corresponding values of α and D/a^2.

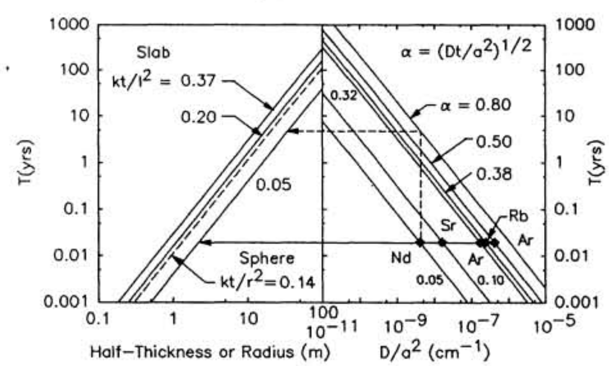

Figure 1. Left side: cooling time; right side: diffusion time. A thermal conductivity $k = 0.004$ cm^2 sec^{-1} is assumed for the LHS.

As described in (1) significant losses of Rb also occurred for all mineral separates relative to corresponding separates of an unheated sample. Although Rb losses for the 800°C samples also may have been influenced by the presence of a contaminating high-K quintessence phase, we do not have a firm basis for identifying contributions from such a phase and have calculated F values for Rb diffusing from the individual mineral separates as though they were monomineralic. These F values are also listed in Table I with the corresponding parameters. Values of D/a^2 calculated for Rb are about an order of magnitude lower than for Ar at 800°C, but are similar to the Ar values at 1000°C implying a higher activation energy for Rb than for Ar diffusion.

In the case of the non-volatile elments Sr and Nd, Nyquist et al. (3) have proposed replacing "fraction lost" with "fraction exchanged" calculated for Sr, for example, from

$$F = \frac{(87/86)_m - (87/86)_{obs}}{(87/86)_m - (87/86)_{wr}}$$

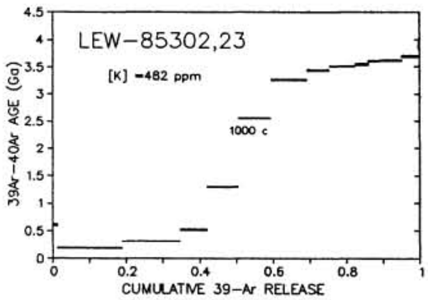

Figure 2. $^{39}Ar-^{40}Ar$ age spectrum eucrite clast LEW85302.

where the (87/86) values are the ones (i) in the mineral (m) before isotopic reequilibration; (ii) observed (obs) after reequilibration, and (iii) the average for the system (wr), respectively. An analogous calculation is used for Nd. Diffusion parameters calculated in this manner are also summarized in Table I for Sr and Nd in plag and px. As expected, the D/a^2 values decrease progressively from Rb to Sr to Nd.

Figure 1 is a nomogram from (2) which relates D/a^2, diffusion time, and fraction lost (via α) to the amount of overburden of rocky material of thermal conductivity $\underline{k} = 0.004$ $cm^2\ sec^{-1}$. The experimentally determined values of D/a^2 at 1000° are plotted on the right hand side of the diagram for the ~1 week experimental diffusion time. As shown on the left hand side, these values of the diffusion parameters could be maintained by the thermal blanketing associated with a few meters of overburden. (The lines shown for various values of kt/l^2 represent different criteria for when the material has cooled sufficiently to stop diffusion (2,3)). Also shown is a hypothetical case illustrating a situation where the sample is maintained at 1000° for sufficiently long to totally reset ($\alpha = 0.8$) the Sm–Nd isotopic system, requiring several years at 1000°C and > 10 meters of overburden.

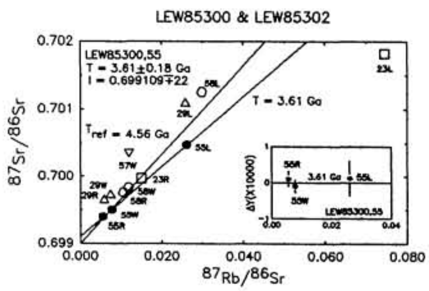

Figure 3. Rb-Sr data for leachates (L), residues (R), and whole (W) samples of clasts from the LEW85300/302 polymict eucrites.

It is reasonable to assume that criteria similar to the above are often satisfied in ejecta blankets on asteroids and the moon. Indeed, from thermal luminescence (TL) studies, Batchelor and Sears (4) conclude that the LEW85302/303 polymict eucrite was shock heated to ≥1000°C. Figure 2 shows the $^{39}Ar-^{40}Ar$ age spectrum for a clast (,23) from this polymict eucrite. The resemblance to the age spectrum for the sample of 15555 artificially heated to 800°C (1) is striking. Thus, the α–values for the natural and artificially heated samples were probably similar. Since the LEW85302 probably achieved a higher initial temperature, and thus higher D/a^2, then the artificially heated sample, it need only have been covered by ~1 m of overburden to achieve the observed degree of resetting.

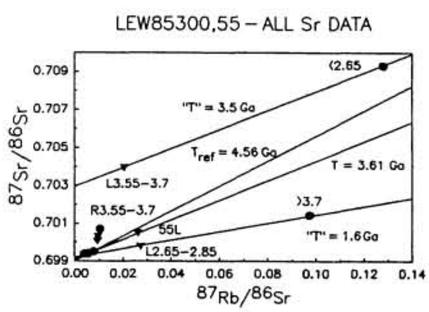

Figure 4. Rb-Sr data for mineral separates of LEW85300,55.

The experimental study implies that age resetting of the magnitude observed in the Ar system should be accompanied by observable effects in the Rb–Sr and Sm–Nd systems as well. Figures 3 and 4 show Rb–Sr data for whole (W), leachate (L) and residue (R) samples from clasts in LEW85300/302. Most of the data are displaced to the left of a 4.56 Ga reference isochron, reflecting recent Rb loss as expected from the observed large Ar loss. The $^{39}Ar-^{40}Ar$ data show that these losses occcurred very recently, ≤0.2 Ga ago. No Rb loss was apparent for clast LEW85300,55 and it was chosen for more detailed study of mineral separates (5, Figure 4). Many of the data thus obtained show the effect of recent Rb loss combined with the more thorough isotopic reequilibration (accompanied by Ar degassing) which occurred ~3.6 Ga ago. The latter event also caused significant disturbance of the $^{147}Sm-^{143}Nd$ system although the $^{146}Sm-^{142}Nd$ system was affected little, if at all (5).

REFERNCES: (1) Nyquist L.E., et al., [1991] this volume. (2) Fechtig H. and Kalbitzer S. [1966] in Potassium–Argon Dating, Springer–Verlag. (3) Nyquist L.E., et al. [1979] Geochim. Cosmochim. Acta, **43**, 1057–1074. (3) Bogard et al. [1979] Geochim. Cosmochim. Acta, **43**, 1047–1055. (4) Batchelor and Sears [1990] LPS XXI, 54–55. (5) Nyquist et al. [1990]. LPSC XXI, 903–904.