RADIOGENIC AND COSMOGENIC ISOTOPES IN LOS ANGELES & DHOFAR 378 SHERGOTTITES.

L. E. Nyquist[1], C.-Y. Shih[2], J. Park[3,4,5], G. F. Herzog[4], K. Nagao[6], T. Mikouchi[7], [1]XI/NASA-JSC, Houston TX 77058 (laurence.e.nyquist@nasa.gov),[2]16406 Locke Haven, Houston, TX 77059 (cshih2014@gmail.com), [3]Kingsborough Comm. Coll., Brooklyn, NY 11235 (Jisun.park@kbcc.cuny.edu), [4]Dept. Chem. & Chem. Biol., Rutgers Univ., Piscataway, NJ 08854, [5]Dept. Earth Planet. Sci., Museum of Natural History (AMNH), New York, NY 10024. [6]Korea Polar Research Institute (KOPRI), 26 Songdomirae-ro, Yeonsu-gu, Incheon 21990, South Korea, [7]Dept. Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.

Introduction: Ikeda et al. [1] described the small (15 g) Martian meteorite Dhofar 378 (hereafter Dho 378) as being similar to Shergotty and other basaltic shergottites. They and later authors noted a close similarity to the Los Angeles stones, the primary difference being in the estimated shock pressures. Shock pressures of 55-75 GPa were estimated for Dho 378 [1], the highest for any Martian meteorite, by comparison to 40-45 GPa for Los Angeles and >45 GPa for ALHA 77005 [2]. Ikeda et al. [1] also described "bubble-like pores" likely formed during impact shock. Such pore spaces may host Martian atmospheric Ne [3,4]. Here we investigate the possibility that radiogenic Nd and Sr as well as cosmogenic Ne and Ar provide additional links between Dho 378 and the Los Angeles stones [5].

Sm-Nd Ages of Dhofar 378 and the Los Angeles Stones: Results of Sm-Nd analyses at JSC of the two Los Angeles stones (hereafter LA#1 and LA#2) were reported by [6] and of Dho 378 by [7]. All three rocks presented significant analytical challenges due to terrestrial contamination and high shock pressures as described in the former reports. Those reports describe measures taken to remove the influence of such effects. Fig. 1 displays the best Sm-Nd data for the three rocks.

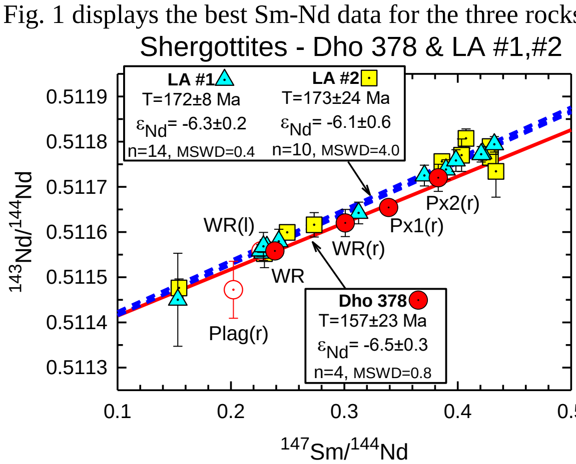

Fig. 1. Sm-Nd data for Dho 378 and the Los Angeles stones.

The data for each rock were regressed individually using the Isoplot program. From the parameters given by that program, the data for LA#1 form a "good" isochron. Individual data deviate from the isochron within ranges expected from the analytical precision, thereby yielding parameter MSWD = 0.4 for 14 samples, an age = 172±8 Ma and ε_{Nd} = -6.3±0.2. The next best and still "good" isochron is given by selected Dho 378 data, whereby one whole rock leachate and one plagioclase analysis with unusually large analytical uncertainty are omitted from the regression. With these omissions MSWD = 0.8 for four samples. The calculated age of 157±23 Ma has uncertainty allowing a crystallization age equivalent to that of LA#1. For 10 samples of LA#2 the MSWD = 4.0 suggesting some post-crystallization disturbances. The calculated age of 173±24 Ma is nominally equivalent to that of LA#1, but a lower age closer to that calculated for Dho 378 cannot be excluded as suggested by Rb-Sr data.

Rb-Sr Results: The Rb-Sr data for the two LA stones are very sensitive to the presence of terrestrial Sr from desert caliche that covered them. Measured $^{87}Sr/^{86}Sr$ is ~0.712 for the caliche compared to $^{87}Sr/^{86}Sr$ ~0.722 for the rocks. All analysed samples were cleaned by acid leaching protocols, and the leachates analysed. The influence of terrestrial contamination is identified among the leachate analyses. Caliche was not specically identifield as present on Dho 378, but a terrestrial contaminant with $^{87}Sr/^{86}Sr$ <~0.713 was identified [7]. The potential presence of residual contaminants on the residues after leaching cannot be *a priori* excluded, but the effect on calculated MSWD values can be observed (Table 1).

Table 1. Rb-Sr isochron results for cleaned samples.

Sample	n	MSWD	T(Ma)	δT(Ma)	I(Sr)	δI
LA# 1	9	30	165	8	0.720995	69
	8	20	165	2	0.720996	59
LA# 2	8	145	169	25	0.720966	140
	6	18	158	11	0.720980	61
Dho 378	4	303	159	250	0.72082	48
Dho 378	4	NA	(157)	NA	(0.72084)	(11)

Regression results from Isoplot.

δT: proportional to isochron slope uncertainty.

δI: uncertainty on last digits for isochron intercept.

Last row: I(Sr) calculated from Sm-Nd age.

For LA#1, 9 samples were identified from preliminary plots of all the data as potentially least affected by contamination. MSWD = 30 was calculated for these samples. Exclusion of a single sample reduced MSWD to 20. In either case, the calculated age is 165 Ma ($\lambda(^{87}Rb) = 1.402 \times 10^{-11}$ yr) within error limits of the Sm-Nd age. We suggest that shock metamorphism produced "geologic" disturbance of the Rb-Sr system because of short-range perturbations of the measured $^{87}Rb/^{86}Sr$ ratio. Analogous perturbations of $^{147}Sm/^{144}Nd$ probably are unobservable. Positive and negative perturbations of $^{87}Rb/^{86}Sr$ are likely to be randomly distributed among the analysed samples.

For LA#2, an MSWD value as low as for LA#1 is only obtained for 6 of the 8 analysed samples. We consider the age of 158±15 Ma calculated for LA#2 to be meaningfully within uncertainty of the 165±7 Ma Rb-Sr age of LA#1.

Rb-Sr results for Dhofar 378. Interpretation of the Rb-Sr data for Dho 378 is challenging. Data obtained both at JSC and at Kobe University (N. Nakmura, p. comm.) show extensive contamination effects [7]. Nevertheless, some of these data may contain important clues distinguishing Dho 378 from the Los Angeles stones. Whole rock $^{87}Rb/^{86}Sr$ <~0.2 in the Dho 378 analyses both at JSC and Kobe are approximately ½ the values of ~0.35-0.41 for both LA#1 and LA#2.

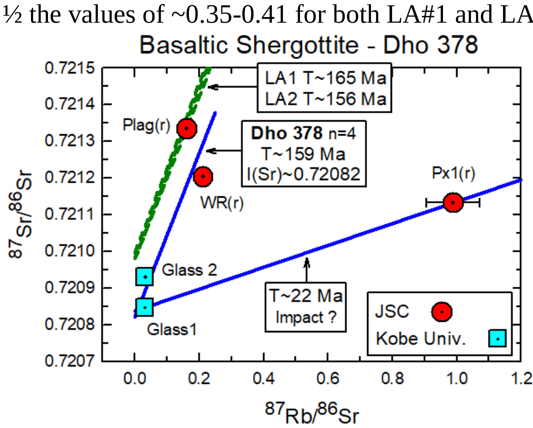

Fig. 2. "Best" Rb-Sr data for Dho 378. (Kobe whole rock data have low $^{87}Sr/^{86}Sr$ because of apparent contamination and fall outside this figure).

Excluding disturbed Px1(r), the other data in Fig. 2 roughly align along a line corresponding to an age of ~159 Ma. It would be unjustified to claim they "determine" an age, but they hint at an initial $^{87}Sr/^{86}Sr$ lower than for the two Los Angeles stones. The same effect is shown by the last line of Table 1, which shows $^{87}Sr/^{86}Sr$ = 0.72084±0.00011 calculated for these data assuming the Sm-Nd age of 157 Ma and assigning the standard deviation of those results as the uncertainty of the mean. That the Plag(r) analysis falls on the Los Angeles isochrons may be coincidental.

Cosmic Ray Exposure Ages: The radiogenic Nd and Sr isotopic data weakly suggest some differences between Dho 378 and the Los Angeles stones, and thus that they may come from different geologic settings. Similarly, the cosmogenic isotope data considered more extensively in [3] weakly suggest that Dho 378 was launched from Mars at a different time than Los Angeles. Fig. 3 is a simplified presentation of the discussion in [3]. It illustrates that for "conventional" (Eugster-Michel = E-M) ^{21}Ne and ^{38}Ar production rates the ^{21}Ne and ^{38}Ar CRE ages for Dho 378 mineral separates and especially whole rocks tend toward lower values than for LA, or for the compositionally similar Ksar Ghilane (KG) 002 shergottite [9]. Correcting for varying chemical composition with Leya-Masarik (L-M) production rates decreases the disparity. Assuming LA and KG samples to be more heavily shielded than the Dho 378 samples further decreases the disparity.

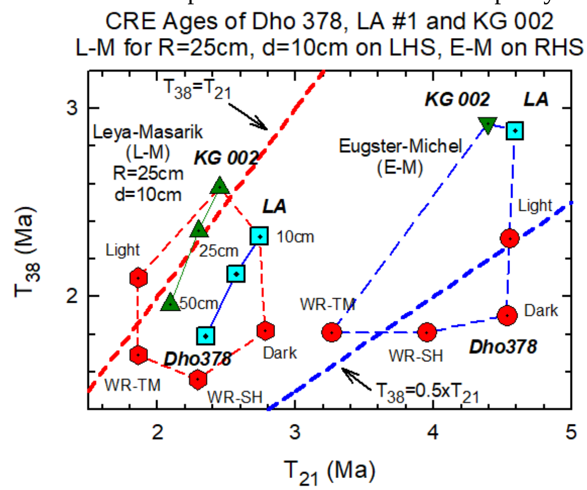

Fig. 3. ^{21}Ne and ^{38}Ar CRE ages for Dho 378, LA#1, and KG 002. If all samples were irradiated at depths of ~10 cm in meteoroids of ~25 cm radius, Dho 378 had a shorter CRE age than LA and KG 002. Irradiation of the latter at ~25 cm depths, or especially at ~50 cm depths in meteoroids of ~50 cm radii could equalize the CRE ages. Llorca et al. [9] suggest a 35-65 cm pre-atmospheric radius for KG 002.

Conclusions: These isotopic parameters extend the similarity among Dho 378, LA, and KG 002, but cannot verify that the rocks were ejected from Mars together. An expansion of the data base to include additional meteorites of similar type might allow more refined conclusions about such potential relationships.

References: [1] Ikeda Y. et al. (2006) *Antarct. Meteorite Res. 19*, 20-44. [2] Fritz J. et al. (2005) *Antarctic Met. Res.*, 18, 96-116. [3] Park J. and Nagao K. (2006) *LPS XXXVII*, Abstract #1110. [4] Park J. et al. (2018) *GCA*,submitted 1344–1345. [5] Rubin A. E. et al. (2000) *Geology*, *28* 1011-1014. [6] Nyquist L. E. et al. (2001) *Eos Trans. AGU 82(47) Fall Meet. Suppl.*, Abstract P51A-02. [7] Nyquist L. E. et al. (2006) *30th Symposium on Antarct. Met. (NIPR)* 89-90. [8] Nyquist L. E. (2000) *Meteoritics & Planet. Sci.*, *35*, A121. [9] Llorca J. et al. (2013) *Meteoritics & Planet. Sci.*, *48*, 493-513.