COSMIC RAY EXPOSURE AGES OF NAKHLITES – NAKHLA, LAFAYETTE, GOVERNADOR VALADARES – AND CHASSIGNY: ONE EJECTION EVENT? E.V. Korochantseva[1,2], S. P. Schwenzer[3,4], A.I. Buikin[1,2], J. Hopp[1], U. Ott[3], and M. Trieloff[1], [1]Institut für Geowissenschaften, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 234-236, 69120 Heidelberg, Germany (e-mail: Mario.Trieloff@geow.uni-heidelberg.de), [2]Vernadsky Institute of Geochemistry, Kosygin St. 19, 119991 Moscow, Russia, [3]Max-Planck-Institut für Chemie, J.-J. Becherweg 27, D-55128 Mainz, Germany, [4]The Open University,Walton Hall, Milton Keynes, MK7 6AA, UK.

Introduction: An important question currently vigorously discussed is if all nakhlites and possibly Chassigny were ejected by the same impact event from a common Martian location [1, 2]. However, the uncertainties of cosmic-ray exposure (CRE) ages are usually high and thus the crucial point in this discussion. Here we present CRE ages for Nakhla (Nak), Lafayette (Laf) and Chassigny (Chas) studied by ^{40}Ar-^{39}Ar dating of irradiated mineral separates and whole rocks. We also report CRE ages for these meteorites and Governador Valadares (GV) using the cosmogenic nuclides ^{3}He, ^{21}Ne, and ^{38}Ar in unirradiated whole rock samples.

Methods: The CRE ages of samples studied by Ar-Ar dating (*Heidelberg*) were determined as described in [3]. These ages and CRE ages using the isotopes ^{3}He, ^{21}Ne, and ^{38}Ar (*Mainz)* were calculated following the method of [4, 5]. The elemental data for production rates (P) were taken from the literature [6-9; and references therein]. No shielding correction was applied for P_{38}. This agrees with [5] who assumed no shielding dependency for ^{38}Ar production in achondrites; however [10] argue differently. The choice of Martian $(^{36}Ar/^{38}Ar)_{trap}$ of 5.35 or 4.0 [11, 12] is not critical (Table 1), as ^{38}Ar is predominantly cosmogenic. For details of the component partitioning see [13, 14].

Results: *CRE age from spectra ($T_{38(Ar-Ar)}$; Fig. 1, Tab. 1).* The errors of CRE ages take into account statistical and analytical uncertainties, e.g., day to day variations in spectrometer sensitivity and Ca to ^{37}Ar conversion factors. Systematic uncertainties affecting all samples in the same way, e.g. affecting absolute argon concentration, or the production rate of cosmogenic ^{38}Ar from Ca, are not included. Hence, the errors are appropriate to check for relative CRE age differences within the samples analysed with the Ar-Ar method and identical shielding conditions, but not realistic for the comparison with CRE ages obtained using ^{3}He or ^{21}Ne (see below), or comparing $T_{38(Ar-Ar)}$ ages of samples with different shielding conditions.

CRE ages determined from the total ^{3}He (T_3), ^{21}Ne (T_{21}), and ^{38}Ar (T_{38}) (Tab. 1). CRE ages for Chas are somewhat variable. In particular, T_{38} appears to be lower than the other CRE ages, as has been observed before [e.g., 5]. For Laf and Nak (1) the three ages lie closer together than for Chas and GV. Two Nak samples are different in their T_{38} ages, but agree within uncertainties in their mean values of T_3, T_{21} and $T_{38(5.35)}$ ages: 12.28±0.73 Ma (Nak 1) and 11.37±1.62 Ma (Nak 2). With the exception of T_{21} of GV our values agree with literature values [5, 15].

Discussion: The $T_{38(Ar-Ar;\ 5.35)}$ value of Nak of 10.35±0.06 Ma agrees well with the mean T_{38} age of 10.65±0.90 Ma of our unirradiated Nak WR samples. Both are also in agreement with the preferred ejection age of 10.8±0.8 Ma from Kr-Kr dating [16]. CRE ages based on different stable noble gas isotopes, however, vary significantly from 8.4 to 16.0 Ma [15]. With few exceptions [17] nakhlite CRE ages determined from ^{38}Ar are younger than those based on He and Ne [2]. We also observe that CRE ages determined from $^{38}Ar_{cos}$ (Table 1, [15]) are systematically lower than CRE ages determined from ^{3}He and ^{21}Ne. One of the reasons for the variation of T_{38} ages could be the application of average P_{38} to possibly heterogeneous mg-sized WR samples used for noble gas studies. On the other hand, the mean T_{38} value of 10.50±1.50 Ma from these studies is much closer to the Kr-Kr CRE age than to the mean T_3 and T_{21} values of 12.51±1.32 Ma and 13.16±1.63 Ma, respectively. The Kr-Kr CRE age was considered by [16] to be more reliable than the CRE ages based on stable noble gas isotopes. The discrepancy between CRE ages determined by Kr-Kr and ^{38}Ar on the one hand, and ^{3}He and ^{21}Ne on the other hand, remains enigmatic.

The $T_{38(Ar-Ar)}$ age of Chas is indistinguishable from the age derived by the Kr-Kr dating method, 10.6±2.0 Ma [16], or the mean value of 10.64±2.89 Ma (2σ) calculated from T_3, T_{21} and T_{38} ages in this study (Table 1). The high uncertainties of the mean T_{3-38} values of Chas [15, our data] are due to considerable scatter in T_3, T_{21} and T_{38} values. Surprisingly, T_3 values of Chas are higher than T_{21} and T_{38} [15, our data] in spite of the higher diffusivity of He.

Our data and the comparison with literature data demonstrate large differences in obtained CRE ages, which underlines the need to improve P evaluations. More precise CRE ages would be crucial to evaluate the hypothesis that nakhlites and chassignites were launched by the same event. In addition, systematic uncertainties in CRE ages could be minimized by comparing results inferred from CRE age spectra based on ^{38}Ar from Ca, where Ca is measured via ^{37}Ar produced during neutron irradiation via the $^{40}Ca(n,\alpha)^{37}Ar$ reaction. This would eliminate errors from measurements of absolute noble gas concentrations (~5%), and P errors from target element chemistry (mostly Ca and Fe, few %). With this, $T_{38(Ar\text{-}Ar;\ 5.35)}$ values of Chas (10.51±0.18 Ma) and Nak (10.35±0.06 Ma) become indistinguishable thus arguing for a single ejection event, while the ejection time of Laf (9.22±0.06 Ma) appears to be different. Adopting different P for the main target elements Ca and Fe would not remove the age difference, as both Nak and Laf cpx have nearly identical Ca and Fe contents and Ca/Fe ratios. A possible reason for an artificial difference in CRE ages could be the presence of Cl-derived ^{38}Ar in the irradiated samples. However, $^{36}Ar/^{38}Ar$ ratios in irradiated and non-irradiated samples show identical cosmogenic-like $^{36}Ar/^{38}Ar$ ratios in the fractions used for CRE age calculations. But a crucial uncertainty remains from the shielding dependency of P_{38} [10], which can introduce an uncertainty on the order of 10%, thus allowing for a single ejection event for Nak and Laf.

Summary: Obtained CRE ages based on stable noble gas isotopes are similar to literature data [5, 15]. However, the overall scatter is considerable for individual meteorites. This compromises the evaluation of the hypothesis if a single ejection event launched all nakhlites and Chas from a confined Martian target area [1, 2]. CRE ages determined using stepwise release age spectra (from ^{38}Ar and neutron induced ^{37}Ar) can minimize systematic uncertainties and relative errors, but errors due to uncertainties in shielding still may be on the order of 10%. The observed inconsistency between CRE ages determined by Kr-Kr and ^{38}Ar on the one hand, and ^{3}He and ^{21}Ne on the other hand calls for an improvement in the determination of production rates.

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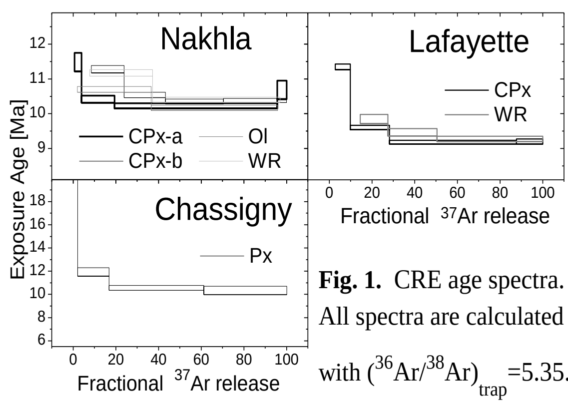

Fig. 1. CRE age spectra. All spectra are calculated with $(^{36}Ar/^{38}Ar)_{trap}$=5.35.

	Chassigny	**GV**	**Lafayette**	**Nakhla (1)**	**Nakhla (2)**
$^{3}He_c$	20.98±1.39	18.64±1.29	19.77±1.50	19.93±1.38	19.45±0.32
$^{21}Ne_c$	3.82±0.22	2.50±0.15	2.12±0.14	2.55±0.14	2.52±0.01
$(^{22}Ne/^{21}Ne)_c$	1.105±0.029	1.158±0.006	1.211±0.010	1.155±0.008	1.143±0.005
$^{38}Ar_c$	0.293±0.011	2.13±0.06	2.20±0.09	2.41±0.03	2.03±0.01
P_3	161.8	162.9	159.9	162.0	162.6
P_{21}	37.96	18.91	18.46	19.65	20.31
P_{38}	3.40	22.99	19.54	20.90	20.90
T_3	12.97	11.44	12.36	12.30	11.96
T_{21}	10.08	13.24	11.50	12.98	12.41
$T_{38\ (5.35)}$	8.86	9.33	11.29	11.55	9.75
$T_{38\ (4.0)}$	8.62	9.26	11.28	11.53	9.70
$T_{38\ (Ar\text{-}Ar;\ 5.35)}$*	10.51±0.18	-	9.22±0.06	10.35±0.06	
$T_{38\ (Ar\text{-}Ar;4.0)}$*	10.43±0.19	-	9.16±0.09	10.26±0.08	
T_{81}**	10.6±2.0	-	-	10.8±0.8	
$T_{3\text{-}38}^{lit}$*** variations / mean value	7.1-15.1 / 11.6±1.6	6.7-12.3 / 10.0±2.1	8.8 -16.0 / 11.9±2.2	8.4 - 16.0 / 12.2±1.5	

Table 1. Concentrations of cosmogenic isotopes (in $\times10^{-8}cm^3STP/g$), production rates (P, $\times10^{-10}cm^3STP/[g\times Ma]$) and CRE ages (T) determined from noble gas analyses. $T_{38(Ar\text{-}Ar)}$ - CRE ages obtained from this ^{40}Ar-^{39}Ar study by CRE age spectra. Literature ^{81}Kr-^{83}Kr CRE ages (T_{81}) and CRE ages based on ^{3}He, ^{21}Ne, ^{38}Ar ($T_{3\text{-}38}^{lit}$) for comparison. All CRE ages are in Ma.

(1) measured in 3 steps like the other nakhlites and Chas; (2) measured in 2007 at Mainz in 5 steps.
***** Laf result is weighted average of WR and cpx, Nak value is weighted average of 2 cpx, ol and WR samples. Weighted errors are 1σ. Error of Ca production rate due to shielding effects not included. Subscripts 5.35 and 4.0 denote $^{36}Ar/^{38}Ar$ ratio of trapped argon used to deconvolute cosmogenic and trapped ^{38}Ar.
** by [16], uncertainties are 2σ; *** by [15], uncertainties of mean values are 2σ.