He, Ne, and Ar *vs.* pre-atmospheric depth in the Murchison meteoroid. J. Park[1,2,3,4], G. F. Herzog[2,3], K. Nagao[5], J. Choi[5], J. M. Baek[5], C. Park[5], J. I. Lee[5], M. J. Lee[5], J. S. Delaney[6,3], B. D. Turrin[6,3], F. N. Lindsay[6,3] and C. C. Swisher III[6,3]. [1]Kingsborough Comm. Coll., Brooklyn, NY 11235, USA (jisun.park@kbcc.cuny.edu), [2]Dept. Chem. & Chem. Biol., [3]Rutgers Univ., Piscataway, NJ 08904, USA, [4]Amer. Museum of Natural History (AMNH), NY, NY 10024, USA, [5]Div. Polar Earth-System Sci., Korea Polar Res. Inst.(KOPRI), Incheon 21990, Korea. [6]Dept. Earth Planet. Sci..

Introduction: Delaney *et al.* [1] searched for evidence of solar heating of the Murchison meteoroid intense enough to cause gas loss during its transit to Earth. To do so they examined the relation between the $^{40}Ar/^{39}Ar$ ages and preatmospheric depths of eight sub-milligram samples, reasoning that shallower depths might lead to greater loss of ^{40}Ar and younger ages. The relative depths were estimated from the activities of the cosmogenic radionuclides ^{36}Cl, ^{26}Al, and ^{10}Be and the aid of modeling calculations [2, 3]. A slight *anti*correlation between depth and integrated age (1.8 - 2.7 Ga) was noted, the opposite of what was expected from solar heating.

A main purpose of this work was to see how noble gas isotopes thought to be more labile than ^{40}Ar behave as a function of preatmospheric depth. Toward that end we measured the stable isotopes of He, Ne, and Ar along with Kr and Xe in a set of 11 Murchison samples including those studied by [1]. A secondary purpose was to determine cosmogenic ^{21}Ne concentrations as part of a reassessment of the cosmic-ray exposure age of Murchison.

Experimental methods: Eleven samples with masses between 18 and 32 mg were preheated at 150 °C for 24 h and then degassed in a single step at 1800 °C for 30 m. The gas released was analyzed mass spectrometrically for He, Ne, Ar, Kr, and Xe at KOPRI [4].

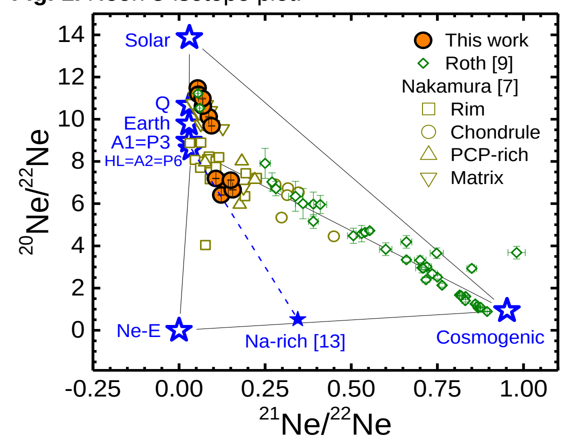
To control for possible compositional effects on the previously measured activities of ^{36}Cl, ^{26}Al, and ^{10}Be [1], we took an aliquot (10-21 mg) from each of the 11 samples for elemental analysis,which was done by ICP-OES.

Results and discussion: The measured elemental compositions are in generally good agreement with published values [5] and the CM-chondrite average of [6] (Table 1). In calculating ^{26}Al activities from measured $^{26}Al/^{27}Al$ ratios, [1] assumed a constant native Al concentration of 1.13 wt% [6] and added the corresponding mass of Al for each sample (~0.6 mg) to that of the Al carrier taken (~8 mg). We have re-calculated those ^{26}Al activities based on the ICP-OES determinations of Al. On average, ^{26}Al activities increase by ~2%.

Table 1. Average composition (wt %)

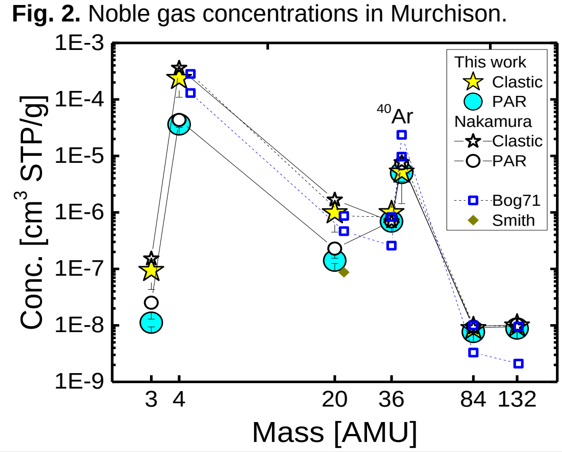
	This work	[5]	CM[6]
Na	0.29±0.12	0.14	0.39
Mg	10.5±0.3	12.02	11.5
Al	1.35±0.13	1.14	1.13
Ca	1.16±0.08	1.35	1.29
Ti	0.060±0.004	0.08	0.06
Cr	0.18±0.09	0.33	0.3
Mn	0.15±0.01	0.15	0.16
Fe	20.5±0.7	22.13	21.3
Co	0.057±0.002		0.06
Ni	1.27±0.05		1.23

Fig. 1. Neon 3-isotope plot.



The measured $^{20}Ne/^{22}Ne$ ratios fall into two clusters (Fig. 1), one with higher values (9.3-12; average 10.7±0.7; N=6) and the other, lower (6.0-7.5; average 6.8±0.3; N=5). When the noble gas concentration data are grouped in this way, averaged by group, and plotted (Fig. 2), the similarities to the laser microsampling results of [7] become evident. In particular, the samples with the higher $^{20}Ne/^{22}Ne$ ratios (Me2572, Me2682A, Me2644 powder, U5461, U5450, U5443) are enriched in ^{3}He, ^{4}He, ^{20}Ne, and to a lesser degree in ^{36}Ar compared to those with lower $^{20}Ne/^{22}Ne$ (Me2684,

Fig. 2. Noble gas concentrations in Murchison.



Me2644B, Me2641, Me2640, and Me5469 powder). Using the terminology of [7, 8], we conclude that the high $^{20}Ne/^{22}Ne$ samples comprise mostly clastic (or matrix) material while the low $^{20}Ne/^{22}Ne$ samples consist mainly of lithic clasts or primary accretionary rocks (PARs). Evidently one or the other lithology may dominate on a spatial scale of millimeters.

Table 2. Average ^{40}Ar [10^{-8} cm^3 STP/g]

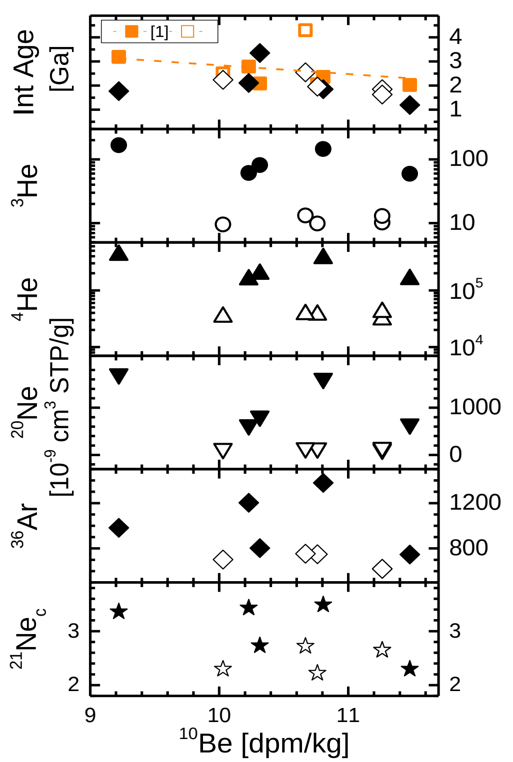
Ref.	Clastic	PAR
[1]	400±200; N=5	208±100; N=2[c]
This work[a]	560±400; N=5	540±90; N=3
This work[b]	520±370; N=6	500±150; N=5
[4]	770±400; N=18	740±500; N=29

a. Samples also analyzed by [1]. **b**. All samples. **c**. Excludes Me2644B. Uncertainties are 1-σ.

The ^{40}Ar concentrations ([^{40}Ar]) in Murchison samples are largely radiogenic [1]. Averages of [^{40}Ar] for PAR and clastic samples agree within the large uncertainties (Table 2). The top panel of Fig. 3 shows similar values and behavior for the closely related integrated (i.e., K/Ar) ages of the clastic and the PAR samples.

The $^{3,4}He$, ^{20}Ne, and ^{36}Ar concentrations do not change appreciably with increasing ^{10}Be activity, which is a a proxy for depth (Fig. 3). Sample U5443 has the lowest ^{10}Be activity, 9.1 dpm/kg, and one of three lowest ^{36}Cl activities, ~ 20 dpm/kg, of the samples studied [1]. According to modeling calculations [2,3], such low activities indicate a relatively shallow preatmospheric depth, <10 cm, for bodies with radii between 20 and 150 cm. Thus, if solar heating affected any sample, it should have been U5443. In fact, its $^{3,4}He$, and ^{20}Ne are among the highest measured (Fig 3). Although younger than the $^{40}Ar/^{39}Ar$ age of [1], the K/Ar age of 1.8 Ga calculated from our new ^{40}Ar with K = 330 ppm [5], is typical of the set. We conclude that surface-enhanced losses due to direct solar heating appear unlikely for U5443.

Fig. 3. Depth (^{10}Be) dependence of ages and gas contents. Symbols: closed=clastic; open=PAR.



We calculated cosmogenic (c) ^{21}Ne for the clastic and the PAR samples assuming solar, A2, and cosmogenic end members for the former and A2, E, and cosmogenic end members for the latter; the results depend only weakly on these assumptions. $^{21}Ne_c$ typically accounts for ~70% of the total ^{21}Ne. On average, the clastic (regolith) samples contain ~ 40% more $^{21}Ne_c$, [10^{-9} cm^3 STP/g] than do the PAR samples: 3.1±0.2 *vs.* 2.2±0.3 (1-σ mean); the latter value agrees with the average of 1.7±0.5 for 39 chondrules [9]. For depth-weighted production rate averages of 2 to 2.5 × 10^{-9} cm^3 STP ^{21}Ne /(g Ma) (R=50 to 150 cm) [2] we obtain cosmic-ray exposure (CRE) ages of about 1 Ma. Herzog et al. [10] obtained a $^{26}Al/^{10}Be$ age, $T_{26\text{-}10}$, of 1.6 Ma based on an assumed $^{26}Al/^{10}Be$ production rate ratio of 2.12 and a ^{10}Be half-life of 1.6 Ma. Use of a lower half-life for ^{10}Be, 1.39 Ma [11], lowers $T_{26\text{-}10}$ to 1.2 Ma. Further consideration of production rates is needed to tighten this result.

Conclusions: The Murchison samples studied have lost >50% of their radiogenic ^{40}Ar in the last 2 Ga. They show no indication of preferential loss closer to the preatmospheric surface, implying minimal diurnal heating effects even for one near-surface sample. A simple possible mechanism for gas loss is long-term diffusion at the relevant, steady-state black- or gray-body temperature(s) [14]. Alternatively, an orbit-related rise in T above 273 K within the last 2 Ga could have melted residual H_2O ice and led to alteration of K-bearing phases (chondrule mesostasis in particular) and localized loss of ^{40}Ar and possibly other gases [1].

References: **[1]** Delaney J.S. *et al.* (2016) *LPS*, 47, 1569.pdf. **[2]** Leya I. and Masarik J. (2009) *MPS*, 44, 1061-1086. **[3]** Kollàr D., *et al.* (2006) *MPS*, 41, 375-379. **[4]** Nagao K., *et al.* (2016) 79th Ann. Mtg Meteorit. Soc., 6109.pdf. **[5]** Jarosewich E. (1990) *Meteoritics*, *25*, 323-337. **[6]** Lodders K. and Fegley B. Jr. (1998) *The Planetary Scientist's Companion*. Oxford U. Press, 371 pp. **[7]** Nakamura T., *et al.* (1999a) *GCA*, 63, 241–255; Nakamura T., *et al.* (1999b) *GCA*, 63, 257-273. **[8]** Metzler K. (2004) *MPS*, 39, 1307-1319. **[9]** Roth A.S.G., *et al.* (2011) *MPS* 46, 989-1006. **[10]** Herzog G.F., *et al.* (1997) *MPS*, 32, 413-422. **[11]** Chmeleff J., *et al.* (2010) *NIM B*, 268, 192-199. **[12]** Bogard D.D. *et al.* (1971) *JGR*, 76, 4076-4083. **[13]** Smith S.P. *et al.* (1978) *EPSL*, 39, 1-13. **[14]** Michel P. and Delbo M. (2010) *Icarus, 209*, 520-534.