

nominal ages have been deduced that increase with grain size and lie in the range ≤ 10 Ma to ~ 130 Ma [2]. But even in this "most favorable" case the results have systematic uncertainties and depend on a number of assumptions [2,3]. Crucial among these is the degree to which spallation-produced Ne is lost due to recoil out of the approximately micrometer-sized grains. We have set out to determine these losses experimentally.

Experimental: Six grain size fractions prepared from commercially available SiC were irradiated in suspension in paraffin wax (~ 2.5 mg SiC/g paraffin), from which they were recovered later. This allows to collect recoil products from the SiC, but avoids back contamination because the wax itself does not yield any spallogenic Ne. The irradiation was performed as a satellite experiment to the irradiation of an artificial iron meteorite [4] with 1.6 GeV protons, in two different positions behind the artificial meteorite, where the relative importance of spallation reactions caused by secondaries was expected to be different.

Results: Retention factors were calculated by comparing spallogenic ^{21}Ne in the recovered grains with that expected from the activity of ^{22}Na in the grains-plus-paraffin mixture. The inferred retentions $\sim 30\%$ for 6- μm -sized grains, $\sim 10\%$ for 3- μm grains, and $<10\%$ for smaller grains — are much smaller than the predictions of the two models discussed in [1]. While model II in [1] is based on a fixed recoil range of 1 μm and otherwise purely geometric considerations, model I is based on calculations by [5], who, according to [1], "have treated the problem more realistically, allowing for range straggling and an accurate relation for the recoil momentum in fragmentation." Our results contradict both predictions. They point to an effective recoil range of the order of 2–3 μm , which implies recoil energies in the MeV range [6] rather than the ~ 0.1 MeV predicted from the treatment in [5].

Discussion: Substituting the observed retention factors into the calculations of [2] leads to presolar ages that are higher than theirs by roughly an order of magnitude. If, in addition, the possible effect of dilution with gas-poor (degassed?) grains [2] is taken into account, inferred ages come close to, or exceed, the age of the universe. We conclude that a determination of a presolar exposure age for SiC via enhancements of ^{21}Ne is not feasible. More promising might be an analogous approach via spallation Xe. Spallation Xe must have been produced on the abundant trace elements Ba and Nd in SiC [7], it should have a shorter recoil range, and there are hints for its presence in the Xe data of [2]. As for the observed differences in $^{21}\text{Ne}/^{22}\text{Ne}$ between different grain sizes of Murchison SiC [2], we submit that the effects of neutron exposure and other nuclear processes operating in the He shell of AGB stars on the isotopic composition of Ne should be reexamined.

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THE SIGNIFICANCE OF HIGHLY SIDEROPHILE ELEMENTS DURING PLANETARY DIFFERENTIATION.

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The platinum-group elements (PGE) Os, Ru, Ir, Rh, Pt, Pd, and Re and Au are collectively named highly siderophile elements (HSE) because of their high metal/silicate partition coefficients, $D_{\text{met/sil}}$. Early (one atmosphere) experimental data suggested metal/silicate partition coefficients of 10^4 to $\sim 10^6$ for Re and Au [1]. In [2], $D_{\text{met/sil}}$ for Ir and Re of about 2×10^4 [1] were reported. Recent experiments produced rather low $D_{\text{met/sil}}$ of Re, from 320 to 3940 [3].

The determination of solubilities of Pd, Au, Ir, Pt, and Os in silicate melts allowed to study the behavior of the HSE in a more systematic way resulting in [4–8]: (1) HSE solubilities decrease with decreasing O fugacity, indicating that HSE are dissolved in the silicate liquid as oxides and not

as metals; (2) there are large differences in HSE solubilities, e.g., at QFM, 1400°C in a melt of anorthite-diopside eutectic composition: Ir (10 ppb), Pt (26 ppb), Pd (7 ppm), Au (2 ppm); (3) the dependence of $D_{\text{met/sil}}$ on melt composition is small.

The $D_{\text{met/sil}}$ calculated from solubilities are much higher than results of earlier experiments ($D_{\text{Ir}} 10^{12}$, $D_{\text{Pd}} 1.6 \times 10^7$; $D_{\text{Au}} 2.5 \times 10^7$, at 1350°C, IW-2). These $D_{\text{met/sil}}$ should be reliable, since activity coefficients in metals required to calculate $D_{\text{met/sil}}$ are reasonably well known. $D_{\text{met/sil}}$ (Pd) depends only weakly on pressure [9] and temperature [4]. A very small amount of metal is sufficient to quantitatively extract HSE from silicates. The small fraction left behind in the silicate has a highly fractionated pattern, e.g., Pd/Ir, Au/Ir of 10^4 – 10^5 . These new data and additional data on sulfide/silicate and olivine/melt partitioning of HSE [10–12] allow a better understanding of their behavior during planetary differentiation.

Earth: The unfractionated HSE-pattern and the small T and p dependence of Pd solubility exclude that the present mantle HSE pattern is the result of metal/silicate equilibration. The low crust/mantle ratios of Ir and Os (~ 0.01) reflect compatibility with olivine. Crust/mantle ratios of Re, Au, Pd, and Ru are between 0.2 and 0.5 [13].

Mars: SNCs show the same basic pattern as the Earth, high HSE in mantle rocks (Chassigny 1.85 ppb, Earth's mantle 3.2 ppb), low and olivine fractionated in Shergotty (Pd/Ir 60.7 in the Earth's crust 66) [14], apparently reflecting addition of a late veneer on Mars.

This suggests the following sequence of events for Earth and Mars: (1) Core formation with quantitative removal of HSE, (2) addition of late veneer and mixing, and (3) crust formation by mantle melting without involvement of sulfides (which would not fractionate Ir-Pd). Fractionation during crystallization of a magma ocean with simultaneous removal of sulfide and/or metal is incompatible with HSE abundances in both planets.

The HSE abundances in the Moon and in eucrites are much lower and more fractionated. The extent of the fractionation indicates that the observed patterns are probably mixtures of residual silicate and metal produced by incomplete separation from the source region.

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SEARCH FOR NICKEL-60 EXCESSES IN PALLASITE OLIVINES.

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We have initiated a search in pallasite olivines for possible excesses of ^{60}Ni due to the decay of ^{60}Fe (half-life 1.5 Ma). The search in pallasite olivines was based on (1) the observation of evidence for the *in situ* decay in pallasite olivine of ^{53}Mn (half-life 3.7 Ma) for Eagle Station [1] and for Omolon [2]; (2) the expectation of high $^{56}\text{Fe}/^{58}\text{Ni}$ in pallasite olivines; (3) Re-Os measurements in pallasites that indicate a whole-rock isochron for pallasites consistent with the whole-rock Re-Os isochron for iron meteorites and possibly early formation [3]; and (4) the discovery of evidence for the *in situ* decay of ^{60}Fe in eucrites [4, 5]. We note that a preliminary measurement of Ni in the Omolon pallasite olivine yielded no excess in ^{60}Ni for a measured $^{56}\text{Fe}/^{58}\text{Ni} = 3000$ [5].

We have separated olivines from a suite of pallasites, and have subjected them to magnetic separation followed by handpicking to obtain gram-sized samples that show no evidence of rust. The surfaces of the olivines (300–500 μm) were also abraded in a wiggle-bug. The quality of the separates was monitored by measurements of Fe/Ni on individual grains using the ion microprobe. Nickel concentrations in olivine show a typical range of factors of 1.5–2, with the lowest concentration of 7 ppm and typical concentra-

tions of 10–15 ppm, with some values ranging up to 24 ppm. For a value of 10 ppm Ni and about 9% Fe, we obtain $^{56}\text{Fe}/^{58}\text{Ni} \approx 12,700$. For the best estimate for the initial $^{60}\text{Fe}/^{56}\text{Fe} = 6 \times 10^{-8}$ [6] we calculate a total possible shift in $^{60}\text{Ni}/^{58}\text{Ni}$ of 20 parts in 10^4 . A much smaller shift would be applicable if the formation of pallasites required more than 5–10 m.y.

We have developed chemical separation techniques for Ni following standard textbook procedures and the description by Birck and Lugmair [7]. For mass spectrometry we modified our ionization techniques for Cr and Fe [8,9]. Nickel (as the nitrate) is loaded on a Re filament with SiO_2 gel and boric acid, with the addition of some $\text{Al}(\text{NO}_3)_3$ to improve ion beam stability, as observed first for Fe [9]. We have analyzed reagent, normal Ni and Ni extracted from Thiel Mountain olivine. Relative to the Ni isotopic composition given in [7] we obtain, for reagent Ni, $^{60}\text{Ni}/^{58}\text{Ni} = -0.98 \pm 0.98 \text{ eu}$; for Thiel Mountain olivine we obtain $^{60}\text{Ni}/^{58}\text{Ni} = -0.9 \pm 2.0 \text{ eu}$ (all uncertainties are $2\sigma_{\text{mean}}$). Therefore, the ^{60}Ni in Thiel Mountain olivine is identical to the normal terrestrial abundance. Based on the uncertainties, and on the measured $^{56}\text{Fe}/^{58}\text{Ni} \approx 12,700$, we calculate an upper limit for $^{60}\text{Fe}/^{56}\text{Fe}$ of about 6×10^{-9} . This limit is comparable to the observed initial $^{60}\text{Fe}/^{56}\text{Fe}$ in the eucrite Chervony Kut [4]. If the Thiel Mountain pallasite had formed on the same timescale as Chervony Kut, from a uniform ^{60}Fe abundance reservoir, we would have been able to resolve an excess in ^{60}Ni . If we consider the evidence provided by Chen et al. [10] that, based on Re-Os, the iron meteorites and the pallasites cooled on a substantially longer timescale of $\sim 10^8 \text{ yr}$, it is unlikely that excesses in ^{60}Ni will be detectable. We will report on additional Ni measurements, as well as on the Mn-Cr systematics in Thiel Mountain and in selected pallasites, and will address the possible conflict between the Re-Os and Mn-Cr data [10].

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ATMOSPHERIC EVOLUTION UNDER DUST BOMBARDMENT AND NOBLE GAS FRACTIONATION IN THE TERRESTRIAL ATMOSPHERES. A. K. Pavlov¹ and A. A. Pavlov², ¹Ioffe Physical Technical Institute, Russian Academy of Sciences, Polytechnicheskaya 26, St. Petersburg, 194021, Russia (pavlov@nspl.ioffe.rssi.ru), ²Faculty of Physical Science and Engineering, Department of Space Physics, St. Petersburg State Technical University, Polytechnicheskaya 26, St. Petersburg, 194021, Russia.

Basing on the earlier proposed process of the effective atmospheric gas losses under accretion of interplanetary dust particles [1], we have considered the evolution of the total noble gas abundance and compositions in terrestrial atmospheres. Changes in the rate of dust accretion and planetary outgassing were taken into account. Gas escape occurs in the process of dust/atomic collisions in the upper atmosphere. It is demonstrated that sticking of the atmospheric atoms in the surface of the dust particles and ablation of the dust particles in the atmosphere are not significant for our escape process.

Effects of inelastic collisions between the dust particles and the atmospheric atoms were considered. Despite the fact that inelastic collisions reduced the efficiency of the gas loss, it remained significant. We describe how this effect was taken into account in the computer simulations.

The same interplanetary dust irradiated by the solar wind was proposed as a possible source of noble gases; this source has a "solar" composition. In the framework of our model the fractionation of the noble gas composition (compared to the "solar" composition of the source) is explained by the more effective escape of Ne and Ar from the terrestrial atmospheres under collisions with the dust particles. It is shown that our model can explain the peculiarities of the noble gas observational data (in planetary atmospheres and meteorites). We have determined that the atmospheric noble gas composi-

tion could change significantly during the period of intensive dust bombardment. The possibility of "capturing" such changes in noble gas in specific meteorites (SNC) is discussed.

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MEASUREMENT OF NEON AND ARGON ISOTOPIC COMPOSITIONS IN SINGLE LUNAR REGOLITH GRAINS. R. O. Pepin and D. J. Schlutter, School of Physics and Astronomy, University of Minnesota, 116 Church Street SE, Minneapolis MN 55455, USA.

The $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{21}\text{Ne}/^{22}\text{Ne}$ ratios in the solar wind (SW) seem fairly well established at 13.8 ± 0.1 and 0.0328 ± 0.0005 from the Apollo foils [1] and acid-etch analyses of regolith samples [2]. Not so for Ar: Current estimates of SW $^{36}\text{Ar}/^{38}\text{Ar}$ ratios range from 5.42 [2] to ~ 5.6 [3,4] and higher [5,6]. These values were obtained from "large" sample masses (usually approximately tens of milligrams) and so are averages over many thousands of regolith particles. Our objective in the present work is to examine the solar irradiation record in individual mineral grains, using the microanalytic mass spectrometric techniques—now extended to include Ar—originally developed by Nier and Schlutter to measure He and Ne thermal release profiles from single IDPs and lunar grains [e.g., 7]. Each of the 11 particles analyzed so far was pyrolytically degassed in ~ 10 – 15 5-s heating steps at temperatures from $\sim 80^\circ$ to 1150°C . Here we restrict the discussion to Ne and Ar releases with $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{36}\text{Ar}/^{38}\text{Ar}$ ratios above ~ 13.7 and ~ 5.7 respectively. In most of the grains these were evolved early in the runs, presumably from near-surface sites, where SW gases would be expected to dominate over deeper SEP [2] and spallation components.

Grain-to-grain variations in the isotope ratios listed in Table 1 suggest normal distributions, although uncertainties are occasionally large. We have therefore used $1/\sigma^2$ weighting in averaging over temperature steps and the entire datasets. Agreement of average Ne ratios with previous SW acid-etch

TABLE 1.

Sample	Release T (°C)	Neon	
		$^{20}\text{Ne}/^{22}\text{Ne}$	$^{21}\text{Ne}/^{22}\text{Ne}$
10084 Ilm	470, 670	13.71 ± 0.20	0.0318 ± 0.0009
67601 Plag	—	—	—
79035 Ilm-1	—	—	—
79035 Ilm-2	150	14.21 ± 0.56	0.0324 ± 0.0036
71501 Ilm-1	150, 470	13.88 ± 0.19	0.0338 ± 0.0005
71501 Ilm-2	875, 1000	13.69 ± 0.10	0.0344 ± 0.0007
71501 Ilm-3	80	13.76 ± 0.71	0.0386 ± 0.0051
71501 Ilm-4	—	—	—
71501 Ilm-5	110, 190, 330	13.88 ± 0.16	0.0308 ± 0.0006
71501 Ilm-6	400, 470, 530, 570	13.95 ± 0.10	0.0331 ± 0.0004
71501 Ilm-7	220, 400, 470, 530	13.96 ± 0.13	0.0337 ± 0.0005
Average ($\pm 1\sigma$)	—	13.85 ± 0.05	0.0331 ± 0.0002
Sample	Release T (°C)	Argon	
		$^{36}\text{Ar}/^{38}\text{Ar}$	
10084 Ilm	470	6.39 ± 0.89	
67601 Plag	180	6.21 ± 0.49	
79035 Ilm-1	220, 330	6.18 ± 0.32	
79035 Ilm-2	150, 330	5.86 ± 0.45	
71501 Ilm-1	470	5.79 ± 0.13	
71501 Ilm-2	470	5.77 ± 1.04	
71501 Ilm-3	80	5.97 ± 0.52	
71501 Ilm-4	150, 470	5.89 ± 0.28	
71501 Ilm-5	110, 190	5.91 ± 0.30	
71501 Ilm-6	470, 820	5.81 ± 0.18	
71501 Ilm-7	220, 400	5.76 ± 0.13	
Average ($\pm 1\sigma$)	—	5.83 ± 0.07	