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Consequences of the non-existence of the “SEP” component for noble gas geo-and cosmochemistry

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Abstract

Lunar and asteroidal regolith samples irradiated by the solar corpuscular radiation have long been thought to contain two isotopically distinct components of solar noble gases, the well-known solar wind close to grain surfaces and a component implanted with higher energies and thus dubbed “SEP” (for solar energetic particles) at slightly larger depth. The apparently large abundance of the “SEP” component has always been very difficult to understand, however. Recently, depth profiles of the isotopic composition of implanted solar Ne into a special target exposed on NASA’s Genesis space mission have unequivocally shown that the depth profiles in the Genesis target and also the extraterrestrial samples can be explained by a depth-dependent isotopic fractionation of the implanted solar wind (A. Grimberg et al., Science 314, 1133–1135, 2006). Hence, “SEP” as isotopically distinct component in extraterrestrial samples does not exist. This contribution discusses some consequences of the elimination of “SEP” from the “noble gas alphabet” for geo-and cosmochemistry.

Keywords: Noble gases; SEP; Solar wind

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1. Introduction

Ever since the first lunar soil samples became available, it was debated whether the surprisingly large variations of implanted solar Ne observed in stepwise extractions (Pepin et al., 1970a,b; Reynolds et al., 1970; Hohenberg et al., 1970) indicate the presence of two isotopically distinct components of solar Ne or whether the data patterns can be explained by fractionation effects on an isotopically uniform solar wind component. The two controversial views have persisted over the years (Black, 1972; Wieler et al., 1986; Frick et al., 1988; Wieler, 1998, Mewaldt et al., 2001), but the hypothesis that lunar soils and gas-rich meteorites contain two isotopically distinct solar Ne components implanted in different energy ranges gained wide acceptance. The low-energy solar wind (SW) component was supposed to reside very close to grain surfaces, whereas the higher energy “SEP” component (for solar energetic particles) would have resided at larger depth. The “SEP” component was also postulated to exist in the four other noble gases (Benkert et al., 1993; Wieler and Baur, 1994). Its reality was widely accepted among noble gas cosmochemists, despite of a major problem. It appeared to be too abundant by several orders of magnitude to be easily reconciled with the present-day flux of particles above the typical solar wind energy range of< 4 keV/amu.

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An important goal of NASA's Genesis solar wind collection mission (Burnett et al., 2003) has thus been to find evidence for or against the existence of "SEP" as isotopically distinct component in the solar corpuscular radiation. For this purpose, a special target made of a metallic glass was exposed on Genesis and later analysed at ETH Zürich by the gas release technique of stepwise in-vacuo etching coupled to on-line mass spectrometric analysis of the evolved noble gases (Grimberg et al., 2006, 2007,submitted for publication). The result of this experiment was – perhaps somewhat surprisingly – unequivocal: the "SEP" component does not exist. The variations of the Ne and Ar isotopic and elemental composition with depth can be explained by separation effects of a uniform solar wind component upon implantation (Grimberg et al., 2006, 2007, submitted for publication). The Genesis mission has solved the almost 40 year old enigma of the "SEP" noble gas component in extraterrestrial samples. In this paper, we thus use the term "SEP" in quotation marks, to express the fact that it should not be viewed any longer as true, isotopically distinct, component. Note, however, that this paper does not discuss the solar energetic particles in the MeV/amu range which are observed in situ by the solar physics community (e. g. Williams et al., 1998) and which are also known by the acronym SEP. Their flux is many orders of magnitude lower than the solar wind particle flux.

The purpose of this paper is to discuss some consequences of the elimination of the "SEP" component from the noble gas alphabet for noble gas geochemistry and cosmochemistry. In the next chapter, we will briefly review the line of reasoning leading to the rise and demise of the "SEP" component. In the following chapters we will then discuss on some key examples how its elimination may require revisiting existing interpretations. The bottom line is that often the main conclusions of a study remain essentially unaffected. If anything at all, it may suffice to replace the term "SEP noble gases" by "fractionated solar wind noble gases". Of course, conclusions about the "SEP" component itself, e. g. its flux or its composition, become obsolete.

2. A short history of the "SEP" component

Whereas in some early publications on lunar samples and solar-gas-rich meteorites the variability of the Ne isotopic composition with extraction temperature was already interpreted to reveal the presence of two isotopically distinct components of solar Ne (Pepin et al., 1970a; Reynolds et al., 1970; Black 1972), the same groups of authors soon cautioned that the data patterns may rather be a consequence of slightly different implantation depths of the different Ne isotopes in the solar wind and isotopic fractionation upon stepwise degassing (Hohenberg et al., 1970; Pepin et al., 1970b).

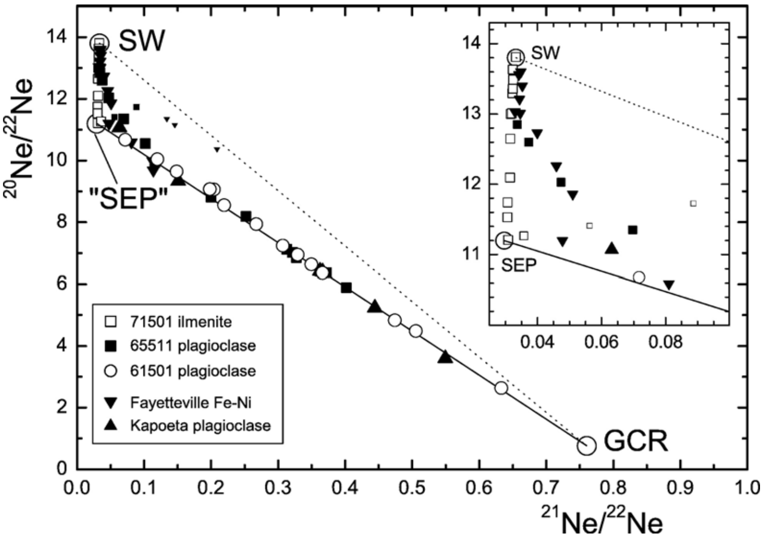

Fig. 1. Ne data from mineral separates from three lunar samples and the two solar-gas-rich meteorites Fayetteville and Kapoeta. Gases were released by in-vacuo etching except for 61501 (total extraction of aliquots etched off-line by Etique et al., 1981). Other data sources are given by Wieler (1998). These and similar data have been interpreted to reveal the presence of "SEP"-Ne as a second solar component isotopically distinct from SW-Ne. In particular the many data points of late gas-release fractions falling apparently on the straight solid line have been interpreted to represent a binary mixture of "SEP"-Ne with Ne produced by galactic cosmic rays (GCR, lower right). Figure adapted from Wieler (1998).

Later, a key argument in favour of the existence of "SEP" have been observations from experiments releasing noble gases by stepwise in-vacuo etching. Data points of late gas fractions released by etching of lunar soils and gas rich meteorites define a linear array in a Ne three isotope diagram (Fig. 1), interpreted as mixing line between galactic cosmic ray produced Ne (GCR, in the lower right in the figure) and a well defined solar Ne component isotopically heavier than SW in deeper grain layers, with $^{20}Ne/^{22}Ne = 11.2$ ("SEP", upper left in the figure). The same line had already been observed in data from lunar plagioclase separates etched off-line to various depths (Etique et al., 1981, Fig. 1), and essentially even earlier in stepwise heating data from solar-gas-rich meteorites (Black, 1972). In other samples, mainly lunar ilmenite separates, the data points of the last major gas fractions often fell close to the "SEP-Ne" point (Benkert et al., 1993). A few heavily weathered Antarctic gas-rich meteorites and some interplanetary dust particles even had a bulk Ne isotopic composition identical to "SEP-Ne" (Padia and Rao, 1986; Pepin et al., 2000). The latter observations were interpreted to indicate a loss of the outermost grain layers, completely removing the SW component but not the more deeply sited "SEP" gas. It was conceived hardly possible that all these data patterns could be the result of processes which fractionate implanted gases continuously with depth. Instead, the data seemed to require a second gas reservoir with fixed composition different from that of the solar wind. Therefore, the "SEP" component was widely accepted, despite the fact that its apparent large abundance always resisted a straightforward interpretation.

A special target was thus selected for Genesis with the goal to rule on the "SEP-enigma". This metallic glass target (Hays et al., 2005; Jurewicz et al., 2003) allowed a very good determination of the depth dependences of elemental and isotopic compositions of implanted noble gases by in-vacuo etching, as it etches very homogeneously (Heber, 2002). Three main observations (Grimberg et al., 2006) led to the conclusion that "SEP" does not exist as isotopically distinct component, but reflects the fact that different isotopes of an element implanted with identical speed distributions have different energies and thus slightly different implantation depths. These observations are: i) the depth profile of the Ne isotopic composition in the metallic glass is very similar to that of the solar Ne in lunar samples. The lowest observed $^{20}Ne/^{22}Ne$ values in the glass were close to the "SEP" $^{20}Ne/^{22}Ne$ ratio of 11.2. In the case of Genesis this clearly cannot be explained by an abundant contribution of solar particles with speeds above the solar wind range of 300–800 km/s, as the solar energetic particle flux during the Genesis mission has been monitored by the Advanced Composition Explorer (ACE) mission; ii) the depth profile of the Ne isotopic composition in the metallic glass can well be reproduced by simulations with the SRIM ion implantation code (Ziegler 2004), for a uniform composition in the solar wind and for the measured SW speed

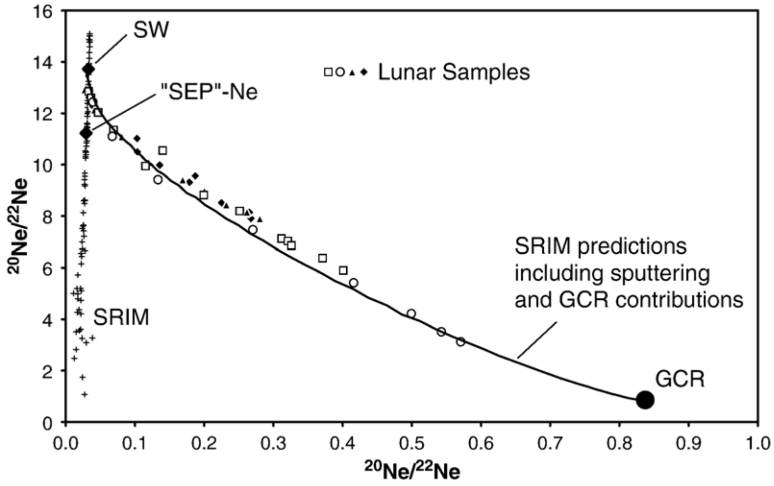

Fig. 2. The figure compares Ne data measured in plagioclase separates from lunar soils (see Fig. 1) with a simulated mixture of neon from the solar wind (SW), fractionated upon implantation to various depth according to the SRIM ion-implantation code (crosses), and Ne produced by the Galactic Cosmic Radiation (GCR). The simulation (solid line) also assumes that the irradiated surface is in equilibrium between solar wind Ne implantation and surface sputtering by SW protons. The data are well reproduced by the simulated mixture, which reflects the fact that heavily fractionated SW Ne at large depths (crosses with $^{20}Ne/^{22}Ne$ ratios below the "SEP" point) is very rare and hardly contributed to the mixture. The figure strongly indicates that the putative "SEP"-Ne component is not required to explain the lunar data.

distribution; iii) the apparent SEP-GCR mixing line observed in lunar samples and meteorites (Fig. 1) is reasonably well reproduced by the metallic glass data, if cosmogenic Ne from a hypothetical GCR irradiation is added (Fig. 2). This can be understood because the most deeply sited gas in the metallic glass with a large enough concentration to be precisely measured has approximately the composition of the putative "SEP" component. More highly fractionated and more deeply sited gas, while undoubtedly present in the glass, is hardly detectable. Grimberg et al. (submitted for publication) show that the depth profiles of $^{36}Ar/^{38}Ar$ and $^{20}Ne/^{36}Ar$ provide additional support for the conclusion by Grimberg et al. (2006), which was based on Ne only.

The "SEP" component could unequivocally be laid to rest thanks to some favourable properties of the Genesis sample in comparison to lunar and meteoritic samples. First, Genesis provided highly controlled exposure conditions, i.e. known fluences of solar energetic particles during exposure time and a precisely known SW speed distribution. Second, no surface-sputter-induced losses or saturation effects had to be considered and no cosmic-ray produced Ne complicated the data patterns. Third, the bulk metallic glass etched very homogeneously, providing high quality depth profiles. No, or hardly any, diffusive losses or diffusive redistribution of implanted solar Ne has occurred.

3. Consequences of the non-existence of "SEP" noble gases for geochemistry and cosmochemistry

Numerous noble gas data sets have been interpreted with the premise that these data represent mixtures of the solar components SW and "SEP", or in some cases even pure "SEP" gases. Examples range from He and Ne in interplanetary dust particles, which partly show bulk isotopic compositions close to the "SEP" value (Pepin et al., 2000), to Ne in the Earth's mantle, which has been proposed by some workers to represent a mixture of SW-Ne and "SEP-Ne" trapped in precursor material of the Earth (Trieloff et al., 2000, Ballentine et al. 2005). In some cases, also nitrogen and oxygen trapped in lunar soil have been thought to represent the "SEP" component (Mathew et al., 1998, Hashizume and Chaussidon, 2005). Here we will discuss on some key examples to what extent such interpretations now need to be revisited.

3.1. Solar noble gases in regolithic samples

Two of the most important pieces of information recorded in lunar and asteroidal regolith are the elemental and isotopic composition of noble gases in the solar wind, and possible long term variations of these compositions. The former is most important for the heavy noble gases Kr and Xe, for which so far no other source of information exists, neither from the aluminum foils exposed on the Moon in the Apollo Solar Wind Composition (SWC) experiment (Geiss et al., 2004) nor from spacecraft data. Possible temporal changes are mainly of interest for the He isotopes since both ^{3}He and ^{4}He are produced in the sun.

The He, Ne, and Ar isotopic compositions in bulk lunar soil samples are heavier than what had been measured in the SWC experiment, which was usually explained either by fractionations due to gas losses from regolith samples or contributions from the "SEP" component or both these processes. However, Wieler (1998) concluded that the true isotopic composition of the noble gases in the solar wind should be reflected by the gases residing at grain surfaces, if ion-implantation and surface loss by sputtering are in equilibrium. This conclusion was based on SRIM modelling and was in agreement with earlier work by Tamhane and Agrawal (1979). It was supported by the fact that the first steps of in-vacuo etch runs of many lunar mineral separates yielded He and Ne isotopic compositions identical to the Apollo SWC values and mass spectrometry data from the SOHO spacecraft (Kallenbach et al., 1997). Recent Genesis data are also in very good agreement with the in-vacuo etch data (Heber et al., 2007, in press; Mabry et al., 2007,in press). Therefore, prior to the Genesis mission, the first steps of in-vacuo etch runs of regolith samples are also widely regarded to provide the current best values for the isotopic composition of Ar, Kr and Xe in the solar wind (Benkert et al., 1993; Becker et al., 1998; Wieler and Baur, 1994), for which no (Kr, Xe) or no precise (Ar) independent values exist. The conclusion that gases trapped at grain surfaces in implantation-sputter equilibrium reflect the bulk solar wind composition should remain valid in the new interpretation of solar gases without the "SEP" component (Grimberg et al., 2006).

However, it is also feasible that some of the discrepancies between different determinations of the isotopic compositions of solar wind Ar, Kr, and Xe are due to isotope separation upon implantation. For example, values between 5.48–5.80 have been reported for the $^{36}Ar/^{38}Ar$ ratio in the SW, based on measurements of near-surface sited gas fractions from lunar soils and gas-rich meteorites (Benkert et al., 1993, Becker et al., 1998; Palma et al., 2002). If analysed samples would not have been in implantation-sputter equilibrium as assumed, reported values would be too high. First analyses of Genesis targets indeed yield $^{36}Ar/^{38}Ar$ values of ~5.50 (Mabry et al., 2007,in press; V. S. Heber, unpublished data), close to the lowest previously reported ratio. Similarly, the considerable difference in the isotopic composition of Kr in the solar wind preferred by Pepin et al. (1995) and by Wieler and Baur (1994), respectively, may partly be due to uncertainties on whether the outermost grains layers or rather the total implanted SW reflect the true SW composition. Genesis targets should soon provide precise data to rule on this.

Geiss (1973) suggested that the $^3He/^4He$ ratio of solar He in lunar samples may exhibit a secular trend. Samples presumed to have been exposed to the solar wind several billion years ago showed an about 30% smaller abundance of ^3He than samples which trapped relatively recent solar wind. Such a trend would not have been unexpected, because a ^3He-rich region gradually evolves at intermediate depths in the solar interior, where temperatures are too low to further process this isotope in the p-p-chains (Bochsler et al., 1990). However, Heber et al. (2003) concluded that the solar wind He isotopic composition has remained essentially constant throughout the past four Ga and hence that mixing of ^3He-rich material into the outer convective zone of the sun must have been very limited. The apparent temporal trend of the $^3He/^4He$ ratio in lunar samples was explained as artefact. Older samples were supposed to have suffered substantial grain surface abrasion, hence not necessarily retaining the true SW composition at the present-day grain surface. One reason for this may be that samples with old solar wind often are regolith breccias, i. e. compacted soil which had to be disintegrated before analysis, thereby probably suffering abrasion of the original grain surface. It is also conceivable that samples stored for a long time in a “gardened” regolith may get abraded well after their last exposure to the solar wind. In Heber et al.’s view, the light gas near the grain surface would have been the solar wind component and the more deeply sited heavier gas the “SEP” component. In the new picture, the gas removed from near the grain surfaces of old samples is nearly unfractionated solar wind, leaving behind fractionated SW Ne favouring the heavy isotopes. Again, however, the fundamental conclusion by Heber et al. (2003) remains unaffected. The solar noble gas record in the lunar regolith therefore shows that no detectable amounts of He produced during the sun’s main sequence stage have been mixed into the outer convective zone. Thus, helium in the solar wind can perfectly be used to deduce the protosolar deuterium abundance (Geiss and Reeves, 1972; Geiss et al., 2004).

Note also that Ozima et al. (2005) offer an alternative interpretation of the data by Heber et al. (2003), according to which part of the noble gas and nitrogen inventory in the lunar regolith stems from the Earth’s atmosphere, implanted at times when the Earth had no magnetic field. Also this interpretation can be maintained, although we note that a very similar correlation between the He and Ne isotopic compositions as in lunar samples is also observed in gas-rich meteorites, samples from asteroidal regolith for which the mechanism proposed by Ozima et al. (2005) cannot work.

As noted above, in essentially all bulk samples of lunar and asteroidal regolith trapped solar He, Ne, and Ar are isotopically heavier than the SW composition measured, e. g., in the Apollo SWC foils or recently in Genesis targets. In some heavily weathered gas-rich meteorites recovered from Antarctic ice, the measured trapped Ne composition is essentially even identical to the “SEP” value (Padia and Rao, 1986), and some interplanetary dust particles also show bulk $^{20}Ne/^{22}Ne$ ratios close to the “SEP” value (Pepin et al., 2000). The original interpretation has been that this is due to a complete – or nearly so – removal of the grain surface layers carrying the SW-component (Padia and Rao, 1986; Murer et al., 1997). In Antarctic meteorites, this would have occurred by weathering, i. e. they would be a natural analogue of regolithic samples severely etched in the laboratory. Grain surfaces from interplanetary dust particles would have been lost during atmospheric entry. Now, these remarkable data are a direct manifestation that indeed the most heavily implantation-fractionated SW which is abundant enough to be measured has a composition close to the former “SEP” value.

3.2. Solar oxygen in lunar metal grains?

Two recent attempts to derive the isotopic composition of trapped solar wind oxygen in metal grains from the lunar regolith yielded conflicting results. Hashizume and Chaussidon (2005) advocate for a ^{17}O-poor composition relative to the terrestrial fractionation line ($\Delta^{17}O \sim -20‰$), whereas Ireland et al. (2006) favour a ^{17}O-rich composition ($\Delta^{17}O \sim +25‰$). Hashizume and Chaussidon argue that the O which they identified to have a solar source represents “SEP-O”, as it appears to reside at depths >100 nm (Fig. 3). As the inference of a relatively abundant “SEP-O” component is inspired by the noble gas analogon, it seems safe to conclude that the interpretation by Hashizume and Chaussidon (2005) of an isotopically distinct “SEP-O” composition should also be abandoned. Rather, the deeply sited O will be strongly implantation-fractionated SW-O. This does not mean, however, that the essential conclusion by these authors must be wrong. The “Solar-SEP fractionation line” in Fig. 3 (Hashizume and Chaussidon, 2005) can simply be relabelled “Solar-O fractionation line”. It is

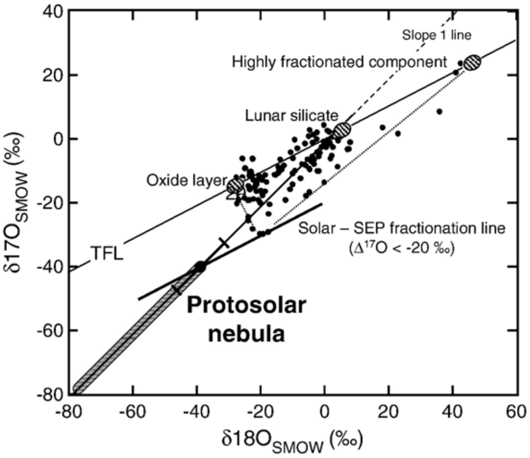

Fig. 3. Oxygen isotopic composition measured in surface layers of several lunar metal grains by Hashizume and Chaussidon (2005). The data are shown as small solid dots, with $^{17}O/^{16}O$ and $^{18}O/^{16}O$ ratios expressed as permil deviations from Standard Mean Ocean Water (SMOW). The large solid dot gives the upper limit of $^{17}O/^{16}O$ and $^{18}O/^{16}O$ of solar wind oxygen derived by Hashizume and Chaussidon as intersection of the "Slope 1 line" defined by calcium-aluminum-rich inclusions (CAI) in meteorites with the line labelled "Solar-SEP fractionation line". The latter line should be relabelled "Solar O fractionation line", but this does not affect the author's basic interpretation of their data. Figure from Hashizume and Chaussidon (2005).

clear that the conflict between the two different reported compositions of SW-O cannot be resolved by the new picture presented here, because neither a fractionation due to implantation nor one due to a partial loss of solar oxygen will affect the $\Delta^{17}O$ values.

3.3. Solar nitrogen and carbon in the lunar regolith

Many efforts have been made to determine the isotopic composition of nitrogen in the solar wind from analyses of lunar regolith samples (e. g. Kerridge, 1975; Clayton and Thiemens, 1980; Frick et al., 1988; Kerridge, 1993), and a few attempts to measure solar wind carbon have also been reported (Becker, 1980; Hashizume et al., 2004). In particular the N data have resisted a straightforward interpretation, because very large variations of up to 30% were observed not only in different samples but also in different gas release fractions of single samples (see reviews by Kerridge, 1993; Becker et al., 2003; Marty et al., 2003). About ten times smaller variations were found for carbon (Becker, 1980). For many years the prevailing interpretation has been that these variations reflect secular changes of the isotopic composition of N and C in the solar wind (Kerridge, 1993; Becker ,1980). Today, most workers seem to agree, however, that non-solar contributions dominate the nitrogen inventory in lunar bulk regolith samples and that the isotopic variations are caused by variable mixing proportions (Wieler et al., 1999; Hashizume et al., 2000; Marty et al., 2003). Depth profiles of N and C isotopes in lunar grains obtained by an ion-microprobe indicate that N and C in the solar wind are depleted in the heavy isotope by at least 24% and by about 10%, respectively, relative to terrestrial values (Hashizume et al., 2000, 2004).

Some of the observed variations in both C and N have been attributed to reflect variable contributions of SW and "SEP" components. For example, Hashizume et al. (2000) infer a value of $<-240‰$ for $\delta^{15}N_{SW}$ and $\sim-120‰$ for $\delta^{15}N_{SEP}$, and Hashizume et al. (2004) postulate $\delta^{13}C_{SW}$ $\sim-105‰$ and $\delta^{13}C_{\text{“SEP”}}$ up to $+10‰$. Once again in analogy to the noble gases, these isotopically heavy components most reasonably are reinterpreted to represent implantation-fractionated SW-N and SW-C rather than isotopically distinct high-energy components. The SW-N and SW-C composition inferred by Hashizume and coworkers are not affected by this reinterpretation, however.

In contrast to Hashizume et al. (2000), Mathew et al. (1998) concluded that "SEP"-N is isotopically lighter than SW-N, in contrast to neon and the other noble gases. This conclusion was based on an observed anticorrelation between $^{14}N/^{15}N$ and $^{20}Ne/^{22}Ne$ in ilmenite separates from a lunar soil etched off-line. However, "SEP" as distinct component being eliminated, this conclusion is not tenable any longer, since fractionation of N and Ne upon implantation will be of the same sign. The interpretation of the anticorrelation observed by Mathew et al. thus needs to be revised. Most likely it is caused by a variable mixture of solar and non-solar N. The steps with less-fractionated (i. e. near-surface-sited) SW-Ne presumably contained a higher proportion of isotopically heavy non-solar N than the steps releasing more heavily fractionated SW-Ne from deeper sites.

3.4. Galactic particles in the lunar regolith, or "HEP" instead of "SEP"?

Wimmer-Schweingruber and Bochsler (2001) proposed a potentially far-reaching hypothesis to explain the "SEP" component, by postulating a galactic rather than a solar origin. They suggested that the lunar regolith does not only trap solar noble gases, but also so-called pick-up ions implanted with higher energies. The latter originated in an interstellar cloud. They had entered the heliosphere as neutral atoms and became ionized by solar wind ions or solar UV photons. Wimmer-Schweingruber and Bochsler (2001) hence cautiously proposed to rename the "SEP" component to "HEP" for "Heliospheric Energetic Particles". One motivation was that galactic particles might also have been able to explain the opposite enrichment or depletion trends of the heavy isotopes in "HEP" between noble gases and nitrogen relative to the solar wind composition. Unfortunately, the attractive possibility that the lunar regolith might preserve records of the isotopic and elemental composition of dense interstellar clouds traversed by the solar system must now be abandoned.

3.5. Solar noble gases in interplanetary dust particles and micrometeorites

Interplanetary dust particles recovered in the upper atmosphere and micrometeorites from polar ice or the seafloor mostly contain noble gases with approximately solar isotopic composition (Olinger et al., 1990; Nier and Schlutter, 1990; Pepin et al., 2000; Kehm et al., 2006). Remarkably, ^{20}Ne/^{22}Ne ratios of the trapped component in some of these particles are close to the "SEP-Ne" value (e. g. Pepin et al., 2000; Kehm et al., 2006). Analogous to the heavily weathered meteorites discussed above, this has been interpreted as being caused by a complete or nearly so removal of the SW component, e. g. by grain surface loss due to weathering or ablation or diffusive losses during atmospheric entry. As with the weathered meteorites, this suggestion has now to be reformulated in that near-surface-sited SW (enriched in the light isotope over bulk composition, due to fractionation upon implantation, Grimberg et al., 2006) has been preferentially removed. Of course, inferences about the flux ratios of solar energetic particles to solar wind and space exposure ages based on the concentration of "SEP" noble gases in interplanetary dust particles become obsolete.

3.6. Solar noble gases in the terrestrial mantle

Ne in terrestrial mantle-derived samples has ^{20}Ne/^{22}Ne ratios between the atmospheric ratio of 9.8 and higher values, with the upper limit observed being close to solar composition. Because atmospheric contamination is ubiquitous and because of possible additions of nucleogenic ^{22}Ne (secondary products from U-and Th-decay, e. g. ^{19}F(α,n)β^+ ^{22}Ne, ^{25}Mg(n, α)^{22}Ne; Leya and Wieler, 1999), the true primordial mantle ^{20}Ne/^{22}Ne cannot easily be determined. Some authors argue for a solar wind-like composition with ^{20}Ne/^{22}Ne around 13.8 or slightly lower (Sarda et al. 1988; Honda et al. 1991; Niedermann et al. 1997; Yokochi and Marty, 2004), suggesting trapping of mantle Ne from the solar nebula, e. g. by solution in a magma ocean (e. g. Mizuno et al., 1980) or through gravitational capture (e. g. Yokochi and Marty, 2004). In this case, the mostly lower measured values would be due to atmospheric or nucleogenic contamination. However, several recent publications argued that frequently measured ^{20}Ne/^{22}Ne ratios in the range of 12.0–12.5 do actually reflect the true upper mantle composition, or at least one major upper mantle reservoir (Ozima and Igarashi, 2000; Trieloff et al. 2000; Ballentine et al., 2005). The value of 12.5 is very close to the nominal composition of the so-called Ne–B component, defined by Black (1972) as the average composition of trapped Ne in solar-gas-rich meteorites. As noted above, Black (1972) interpreted Ne–B as mixture of SW-Ne and "SEP"-Ne. Because of the coincidence of the inferred composition of terrestrial mantle Ne and trapped solar Ne in extraterrestrial regolith, Trieloff et al. (2000) and Ballentine et al. (2005) concluded that the terrestrial Ne has been acquired as a solar component originally trapped in accreting material and being a mixture of SW-Ne and "SEP"-Ne. In the new picture presented here, "SEP"-Ne will once again have to be replaced by "implantation-fractionated SW-Ne", but this does not necessarily affect the essence of the conclusion by Trieloff et al. (2000) and Ballentine et al. (2005). The mantle ^{20}Ne/^{22}Ne ratio being lower than the SW-value can be explained by preferential loss of light SW-Ne portions close to grain surfaces prior to accretion. However, we would like to caution here that the similarity of the inferred upper mantle Ne composition (^{20}Ne/^{22}Ne$=12.49\pm0.04$; Holland and Ballentine, 2006) with Ne–B (^{20}Ne/^{22}Ne$=12.52\pm0.18$; Black, 1972) should not be overinterpreted. It is not clear that the average fraction of isotopically light solar Ne lost from grain-surface layers in early solar system material accreting eventually to the Earth should be very similar as it is today in asteroidal and lunar regolith. In the lunar regolith, the average trapped Ne composition is mineral-dependent (Signer et al., 1977), the solar wind speed distribution and hence mean implantation depths may also have been different in the early sun compared to today, and grain surface loss processes might also have been substantially different. On the other hand, an origin of solar-like noble gases in planetary and asteroidal interiors through trapping of solar-wind irradiated accretionary material has also been proposed based on other evidence (Podosek et al. 2000; Busemann et al. 2003, 2006).

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