NOBLE GASES IN THE METEORITE FAYETTEVILLE AND IN LUNAR ILMENITE ORIGINATING FROM SOLAR ENERGETIC PARTICLES.

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Introduction: In earlier studies we presented evidence for a trapped Ne component different from solar wind Ne (SW-Ne) in lunar soils (1, 2, 3). This Ne was found in plagioclase and pyroxene grains of which the outermost, SW gas bearing layers had been removed, mainly by Closed System Stepwise Etching (CSSE).

The component was attributed to Solar Energetic Particles (SEP), i.e., ions emitted by the sun with energies exceeding those of the SW. SEP-Ne was deduced to have a 20-Ne/22-Ne ratio of 11.3 ± 0.3. The large abundance of SEP-Ne lead us to postulate that it represents only in part solar flare (SF) ejecta, while the major fraction is due to particles with energies in between those of SW and SF ions (3).

We are now extending our studies in two directions: * Analyses of solar gas bearing meteorites are expected to show whether the apparent isotopic difference between SEP-Ne in lunar samples and so called Ne-C (20-Ne/22-Ne = 10.6 ± 0.3) is confirmed by CSSE. The latter component was attributed to implanted solar flare particles (4). * Investigations of ilmenite separates from lunar soils, a mineral which retains solar He and Ne considerably better than pyroxene and especially plagioclase. Trapped gases in ilmenite are thus less susceptible to potential elemental and isotopic fractionation caused by diffusion.

Gas extraction: A Fayetteville bulk sample was etched with HNO₃ in the previously described glass extraction line (3). For efficient etching of ilmenite we constructed an HF resistant line, where sample and etchant are contained in a system consisting of gold and platinum only. Blank values for a typical step duration of one hour are 1.5E-11 cm STP both for 4-He and 20-Ne, and 2E-10 cm STP for 40-Ar. He and Ne blanks are thus two orders of magnitude lower than those obtained in the glass line.

Results and Discussion: 250 mg of a finely crushed bulk sample of the dark portion of the Fayetteville H4 chondrite were analyzed. The Ne data are shown in Figure 1a. The sample was subjected to an increasingly aggressive treatment to ascertain the release of measurable gas amounts in all steps. In the first 17 steps the sample was exposed to HNO₃ vapour at room temperature. In steps 18 - 23 etching was performed by liquid acid at room temperature, whereupon the acid was heated up to 80 Degrees C. The path displayed by the data points in Figure 1a reflects these different treatments performed on a sample consisting of a mixture of different minerals: The data points of the "vapour" steps display a pattern similar to those observed from lunar soil plagioclase (3): A steep decrease of 20-Ne/22-Ne from a starting value of 12.7 towards about 11.2 is followed by several steps whose data points fall on a straight line. This line passes through the point representing GCR-Ne as present in light clasts of Fayetteville. To the left, the line extrapolates at 21-Ne/22-Ne = 0.03 to a 20-Ne/22-Ne value of 11.2 ± 0.1, identical to the composition of SEP-Ne found in the lunar samples. The points of steps involving liquid HNO₃ at room temperature scatter, presumably because of the onset of etching of more acid resistant sites, still

![Figure 1: Ne three-isotope diagrams of closed system etching data of a sample of the dark portion of the Fayetteville chondrite (a) and two ilmenite separates of lunar soil 71501 (b). Numbers or characters close to data points indicate the step sequence. SW: Solar wind Ne as measured in the SWC experiment (Ref. 8). GCR: Galactic cosmic ray produced Ne. SEP: Composition of Ne from solar energetic particles in Fayetteville as deduced by data of "vapour" steps 11 - 17. Line 'a' in Figure 1b is the linear best fit through data points 1 - 11. The slope of the line indicates the presence of a trapped Ne component with 21-Ne/22-Ne 0.029, smaller than the SW-value. This component is presumably SEP-Ne.](image-url)
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containing SW-Ne. In the first "hot" steps, Ne with progressively higher 20-Ne/22-Ne ratios and lower 21-Ne/22-Ne ratios were observed. This presumably reflects the dissolution of the most readily etchable minerals, which released the bulk of their cosmogenic Ne up to step 27. In addition, more and more retentive sites still bearing SW-Ne were also etched. The highest 20-Ne/22-Ne ratio recorded is about 13.3, identical to the value observed in the first CSSE step of a lunar pyroxene (3). Evidently, in step 31 rather pure SW-Ne was released. Data from the following steps may be explained as a mixture of SW-Ne, SEP-Ne and small amounts of cosmogenic Ne being freed from sites resistant to acid vapour and cold liquid acid. At the time of this writing, the etching of these resistant sites is still going on.

The data points of the last seven "vapour" steps fall along a straight line connecting two well known components, namely SEP-Ne as found in lunar soil minerals and GCR-Ne. This argues against the presence of SW-Ne from the more acid resistant sites in these steps. We thus postulate that SEP-Ne in Fayetteville has a 20-Ne/22-Ne ratio of 11.2 ± 0.1, identical to the value found in the lunar samples.

This run yielded the first CSSE data possibly allowing to deduce the isotopic abundance of SEP-He. 4-He/3-He ratios continuously increase from step 1 to step 11 from about 2500 up to about 4200. A plateau at this value is observed for all steps which released nearly pure SEP-Ne (steps 11–14). This seems to indicate that SEP-He is isotopically heavier than SW-He, with a 4-He/3-He ratio of about 4200 or slightly higher, because a small admixture of cosmogenic He may have somewhat reduced the plateau value.

Different 4-He/3-He ratios of solar gases trapped in early and recently exposed lunar soils were observed and attributed to a secular decrease of 4-He/3-He in the solar wind (5). If SEP-He is indeed isotopically heavy, the observed trend could alternatively be explained by the effect postulated to cause the slight secular increase of the 20-Ne/22-Ne ratio of trapped Ne, namely a decrease of the SEP/SW flux ratio with time (6). The substantially more pronounced effect found for He is then simply the result of the larger isotopic abundance difference between SEP-He and SW-He.

Satellite borne instruments measured 4-He/3-He ratios as low as about 1 during many solar flare events (e.g., 7). SEP-He with 4-He/3-He around 4200 would imply that this component in extraterrestrial samples is drastically different from the SF-He detected by satellites.

The 36-Ar/38-Ar ratios observed in steps 11–14 are compatible with this ratio with SEP-Ar being around 5.2, i.e., slightly lower than the SW value of about 5.4. Admixture of cosmogenic Ar, which is difficult to correct for, prevents clear cut conclusions.

Two ilmenite separates of lunar soil 71501 (grain size around 150 μm, sample weight about 4 mg) were measured. The samples were already efficiently etched by HF vapour. The Ne data are given in Figure 1b. Points of steps a –d of the first sample all cluster around the solar wind value and indicate thus the presence of unfractionated SW-Ne. These steps released a cumulative fraction of about 10% of the total gas in the sample. Unfortunately, nearly all the remaining gas was freed in the subsequent step e.

The second sample was etched with HF vapour pressure reduced by cooling the acid (steps 1–15). This run had to be terminated because of a leaking valve. At this time, at least 70% of the Ne in the sample had been released. Steps 1 – 11 fall on a straight line with a positive slope, similar to the line defined by the data of a pyroxene separate from the same lunar soil (3), whereby the latter sample released in the last few etching steps nearly pure SEP-Ne (20-Ne/22-Ne = 11.3). This is not the case here. Presumably, in the last 3 – 4 steps more acid resistant sites were attacked, tapping a new SW-Ne reservoir. In these steps also a larger fraction of grain volume was dissolved, as is made evident by the release of considerable amounts of volume distributed cosmogenic Ne. Up to the forced termination of the ilmenite run it has thus not been possible to observe pure SEP-Ne as in lunar pyroxene and in Fayetteville. All steps contained SW-Ne besides the presumed SEP component. Despite these reservations, the linear array 'a' in Figure 1b formed by steps 1 – 11 is a clear indication that besides SW-Ne a further trapped Ne component is present in lunar ilmenites. If SEP-Ne is accepted as the obvious candidate for this component, the positive slope of line 'a' shows that SEP-Ne has a 21-Ne/22-Ne ratio smaller than the SW value, as was already concluded on the basis of the pyroxene data (3). Extrapolation of line 'a' to 20-Ne/22-Ne = 11.3 yields a 21-Ne/22-Ne ratio of about 0.029 for SEP-Ne.

He released by the ilmenite is also compatible with a 4-He/3-He ratio of SEP-He as deduced above from the Fayetteville data.

Summary: Trapped Ne with a 20-Ne/22-Ne ratio of 11.2 ± 0.1 has been identified in the gas rich meteorite Fayetteville by closed system stepwise etching. This value is within error limits the same as that found for SEP-Ne in lunar plagioclase and pyroxene separates. Possible temporal - or spatial - variations of the SEP-Ne composition are thus not indicated. He with 4-He/3-He ≈ 4200 was released together with rather pure SEP-Ne. If this can be identified as SEP-He, the secular change of the isotopic composition of He trapped in lunar soils can be explained by a decrease of the SEP/SW flux ratio proposed earlier (6). A first etching study on a lunar ilmenite separate revealed a second trapped Ne component - most likely SEP-Ne - with lower 20-Ne/22-Ne and 21-Ne/22-Ne ratios than SW-Ne.