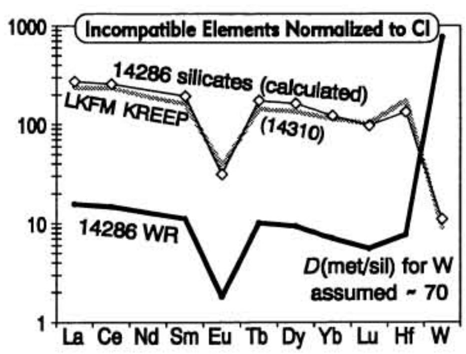
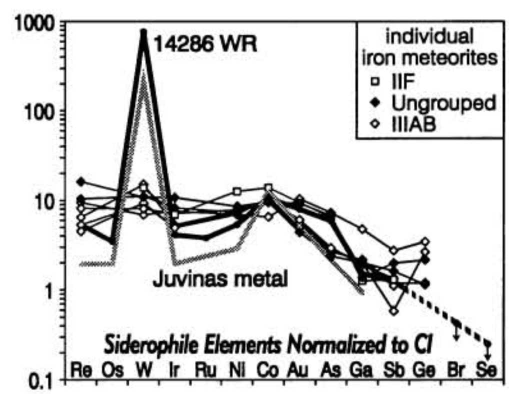
TRACE ELEMENTS, ^{26}Al AND ^{10}Be, AND NOBLE GASES IN LUNAR ROCK 14286; A. Albrecht[1], G.F. Herzog[1], J. Klein[2], R. Middleton[2], L. Schultz[3], and H.W. Weber[3], G.W. Kallemeyn[4], and P.H. Warren[4]. [1]Dept. Chemistry, Rutgers Univ. New Brunswick, NJ 08903; [2]Dept. Physics. Univ. Pennsylvania, Philadelphia, PA 19174; [3]Max-Planck-Institut für Chemie, 55020 Mainz, Germany; [4]Inst. Geophysics & Planetary Physics, Univ. California, Los Angeles, CA 90024.

Introduction - The 4.4-gram lunar rock 14286 is an archetypal sample of lunar metal. It consists mainly of kamacite with 4.7-6.2% Ni and 0.51-0.63% Co [1]. The rest, perhaps 10% by volume, comprises sub equal proportions of maskelynitized plagioclase and pyroxene, both medium-grained, and a partial coating of fine-grained regolith breccia. Warren et al. [1] noted especially the silicate texture in 14286 as evidence for a prolonged period of crystallization, most likely in a melt pool created by a large meteorite impact. The time and circumstances of 14286's arrival on the Moon are of interest. Here we develop constraints on the rock's history through analyses of trace elements by INAA, of ^{26}Al and ^{10}Be by accelerator mass spectrometry, and of noble gases by static mass spectrometry.

Results and discussion - The patterns of CI-normalized distributions for incompatible elements in 14286 (whole rock) and LKFM KREEP agree well (see figure). These results and FeO/MnO systematics [1] strongly imply that the silicate in 14286 is lunar. Overall, the distribution of (mainly) siderophile elements in 14286 (see figure) resembles that in iron meteorites and in metal from the eucrite Juvinas [3], and to a lesser extent that in highlands regolith samples. No match is perfect. The abundances of W and Ga vary most among the sample groups. Tungsten is highly enriched in 14286, regolith, and Juvinas metal, but not in iron meteorites. This observation confirms the petrographic inference that the metal in 14286 experienced an extended, high-temperature interaction with silicate. The Fe/Ni ratio of 14286, ~13, is close to those in group IIIAB, and IIF iron meteorites, and the metal found in E chondrites; however the Au/Ni and Sb/Ni ratios do not match those of E-chondrites. Ga in 14286 is lower than expected, perhaps because of persistent mobility and decreased siderophile character at low temperatures.





The ^{26}Al/^{10}Be ratio of the metal-rich material indicates a low level of silicate contamination in the sample taken for AMS. Although 14286 was collected from the lunar surface, the ^{10}Be and ^{26}Al activities of both metal and silicate (Table 1) are less than the values expected for a long exposure at a surface. This result rules out the possibility that 14286 arrived on the Moon as part of a small meteorite or as a near-surface sample of a large one any time in the last few million years. The observed activities are most simply explained by 1) an irradiation for more than 5 My at a depth of

Table 1. ^{26}Al and ^{10}Be in lunar rock 14286

	^{26}Al	^{10}Be
Silicate		
Measured (dpm/kg)	50.1	5.3
$P_{2\pi}$(surface; GCR) (dpm/kg)[1]	59	12
Measured/$P_{2\pi}$(surface)	0.85	0.44
Metal		
Measured (dpm/kg)	0.74	0.94
$P_{2\pi}$(surface)(dpm/kg)[1]	1.9	2.5
Measured/$P_{2\pi}$(surface)	0.39	0.38

1) Taken as 0.5× production rates of [2].

Table 2. Noble gases (10^{-8} cm^3 STP/g) in metal-rich material from 14286

^{3}He	^{4}He	^{20}Ne	^{21}Ne	^{22}Ne	^{36}Ar	^{38}Ar	^{40}Ar
604	67950	177.2	9.74	23.81	39.2	38.9	140
682	70350	839.2	12.3	81.1	139.8	59.0	902

about 220 g/cm^2 in the Moon [4] followed by 2) excavation and a near-surface exposure that lasted long enough for continued irradiation to raise the ^{26}Al activity of the silicate by about 26 dpm/kg, i.e., 0.16 to 0.10 My for an arbitrarily assumed surface production rate of 200 to 400 dpm/kg. Note that solar cosmic rays do not produce appreciable quantities of ^{26}Al in metal or of ^{10}Be in silicate [5] or metal. The noble gases in 14286 (Table 2) include both trapped and cosmogenic components, which were resolved assuming: solar/cosmogenic ^{22}Ne/^{21}Ne = 32/1.1; ^{36}Ar/^{38}Ar = 5.32/0.65. Cosmogenic ^{3}He = 567 × 10^{-8} cm^3 STP/g was obtained from the intercept of a plot of ^{4}He/^{3}He vs. 1/^{3}He. The average cosmogenic ^{21}Ne and ^{38}Ar contents are 9.7 and 36.6 10^{-8} cm^3 STP/g, respectively.

Table 3. Exposure ages (Gy) of 14286

	T_3	T_{21}	T_{38}	Average.
Moon				
d=0 g/cm^2; R=∞	1.05	0.74	0.85	0.88±18%
d=60 g/cm^2; R=∞	1.79	1.57	1.44	1.59±12%
Iron meteoroid				
d=5 cm; R=5 cm	0.71	0.50	0.52	0.58±20%
d=40 cm, R=40 cm	1.04	0.92	0.75	0.90±16%

Because production rates are not well known for metal, the noble gas data constrain the total exposure age only to within a factor of two. Use of the production rates of [6] for elemental Fe at the lunar surface yields discordant ^{21}Ne and ^{38}Ar exposure ages of 2.3 and 1.3 Gy. Higher ^{21}Ne and ^{38}Ar ages calculated for other assumed depths also disagree by a factor of two or more. Concordant ages are obtained with these production rates if we assume the presence in the metal-rich sample of 3% silicate with the composition of 14310 [e.g., 7]. The maximum possible average depth of exposure is then about 175 g/cm^2, which corresponds to an age of 4.5 Gy. The minimum exposure age, calculated assuming irradiation at the surface, is 0.9 Gy. Fortuitously, exposure ages based on the recent production rates of R. Michel (pvt. comm.; Table 3) for Fe only in the Moon agree well with these values. An alternate view, that 14286 acquired its noble gases in a small-body irradiation of an iron meteoroid lasting for the times given in Table 3, requires that 14286 retained noble gases when it struck the Moon and accreted its silicate rind. Whether or not such retention occurred, it seems likely that lunar noble gases overprinted, at least, any meteoroidal originals. All in all, a small-body irradiation as the source of the cosmogenic gases seems improbable though not impossible. Our lower bound on the cosmic ray exposure for a large-body irradiation, 0.9 Gy, is higher than the 0.65 Gy exposure ages typical of many iron meteorites. The exposure age is also high for a lunar rock but unexceptional for an individual particle in lunar soil [8].

Conclusion - Compositional data indicate a lunar origin for the silicate in 14286. Textural observations and compositional data show that metal and silicate interacted at high-temperature for a prolonged period. Cosmogenic nuclide and solar gas concentrations require a complex exposure history with two recent stages in a large body, probably in the lunar regolith, where such exposure histories are typical. Assuming that all cosmogenic nuclides are lunar, the total exposure of 14286 to cosmic rays lasted at least 1 Gy.

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