THE FIRST LUNAR MAP OF THE AVERAGE SOIL ATOMIC MASS.

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Introduction: Measurements of indexes of lunar surface composition were successfully made during Lunar Prospector (LP) mission, using the Neutron Spectrometers (NS) [1]. This capability is demonstrated for fast neutrons in Plates 1 of *Maurice et al.* [2] (similar to Figure 2 here). Inspection shows a clear distinction between mare basalt (bright) and highland terranes [2]. Fast neutron simulations demonstrate the sensitivity of the fast neutron leakage flux to the presence of iron and titanium in the soil [3]. The dependence of the flux to a third element (calcium or aluminum) was also suspected [4]. We expand our previous work in this study by estimating fast neutron leakage fluxes for a more comprehensive set of assumed lunar compositions. We find a strong relationship between the fast neutron fluxes and the average soil atomic mass: <A>. This relation can be inverted to provide a map of <A> from the measured map of fast neutrons from the Moon.

Neutron physics: Planetary neutrons are produced by interactions between galactic cosmic rays and the nuclei of surface material. The size of a nucleus is related to its atomic mass, and therefore the reaction rate between galactic cosmic rays and soil nuclei is expected to be a function of <A>. The transport of all the secondary particles produced in the soil has two effects. First, numerous new neutrons are produced (mainly by pions and high-energy primary neutrons). Second, a fraction of these neutrons escape toward space, creating the leakage flux that can be measured from orbit.

Neutron leakage flux: The leakage flux is the result of the equilibrium neutron spectrum in the soil and the transport of these neutrons to the surface and beyond. This transport depends on multiple interactions with the nuclear contents of the medium. The resultant spectrum presents broad peaks and relatively narrow resonance absorption structures [3]. Nevertheless the integrated effect of these structures is expected to be small in comparison with the <A> effect on the production. With the help of numerical simulations, we established a strong (correlation ~0.9) linear relation between <A> and the fast neutron leakage flux at the surface (Figure 1). Fast neutron spectroscopy can therefore provide a measurement of the average soil atomic mass.

Measurements: LP measurements at various altitudes were previously combined to obtain a single fast neutron data set [2]. This set gives the integrated neutron flux between about 0.6 and 8 MeV expressed as

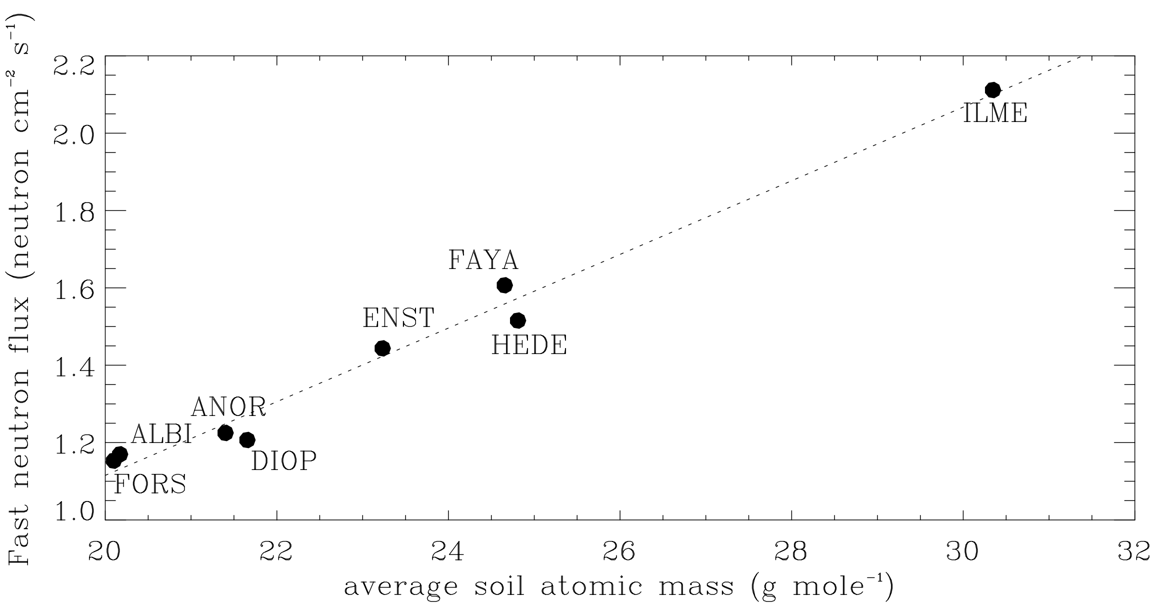

Figure 1. Integrated neutron leakage flux for compositions representing the poles of typical lunar minerals.

effective counts at 100 km altitude per 32 s, which is the integration time for measuring each fast neutron spectrum. Those measurements are well explained by the previously established relationship between fast neutron fluxes and <A>. Indeed LP observations show the mare (rich in heavy elements such as iron and titanium) with relatively high counts, and the highlands (rich in lighter elements such as aluminum and calcium) with relatively low counts.

Extreme soil compositions. The lunar crust can be represented using only four minerals: olivine, pyroxene, plagioclase and ilmenite [5]. Figure 1 shows the simulated leakage fluxes for soils made of these minerals (anorthite and albite for the plagioclases, forsterite and fayalite for olivine, hedenbergite, diopside and enstatite for the pyroxenes, and ilmenite). We do not expect to observe these compositions in their pure forms but a combination of them. In the lunar samples, the rocks from the Apollo 16 landing site soil contain a mixture that has the lowest <A> ~21.5 g mole^{-1}, which is also equal to <A> for ferroan anorthosite (FAN, largely contained in the highlands). A higher <A> is found for the samples from Apollo 11 landing site mare basalts: ~23.5 g mole^{-1}.

Measurement inversion to give <A>. Because we have demonstrated that the fast neutron leakage flux increases linearly with <A>, we therefore assume that the lowest count accumulation (379.7) is associated to the lowest expect <A> (21.5), and the highest count accumulation (494.9) is associated to the highest <A> (23.5). Using this gross calibration, we can produce the first lunar map of <A> (Figure 2).

Discussion and conclusion: Figure 2 is, of course, very similar to the fast neutron map presented by *Maurice et al.* [2]. Figure 2 is projected on a 2^ox2^o equal-area pixel distribution. Although the resultant <A> values are not directly related to the specific gravity, both quantities are closely associated and would be equal if the sub granular porosity was nil.

At first sight, the distinction between highland and mare basalt terranes occurs around 22.5 g mole^{-1}. The highest values are found in the north part of Oceanus Procellarum. The lowest values are scattered in the highlands.

The values of <A> given here are preliminary because we arbitrarily assigned the lowest and the highest <A> values to FAN and the Apollo 11 mare basalt respectively. To improve our estimation, we have to include the instrumental response, which is under investigation.

References:

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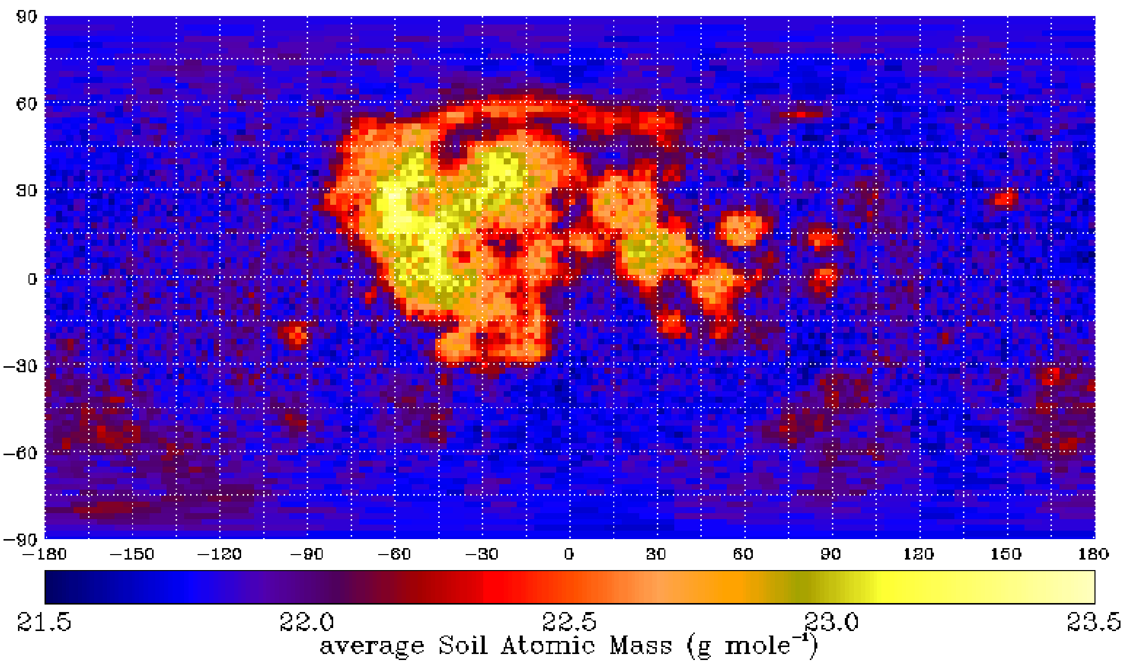

Figure 2. Approximative calibration of the fast neutron map as a measure of the average soil atomic mass <A>.