LUNAR GEOCHEMICAL KNOWLEDGE FROM FAST NEUTRON DATA. I. Genetay[1], O. Gasnault[2], S. Maurice[1], R. C. Elphic[2], W. C. Feldman[2], D. J. Lawrence[2], P. J. Lucey[3] and A.B. Binder[4], [1]Observatoire Midi Pyrénées, 14 avenue Edouard Belin, 31400 Toulouse, France, [2]Los Alamos National Laboratory, MS-D466, Los Alamos NM 87545, USA, [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, USA, [4]Lunar Research Institute, 9040 South Rita Road, Tucson, Az 85747, USA.

Introduction: Lunar Prospector's Neutron Spectrometer provided the first planetary fast neutron data [1]. It was already noticed that the flux of these high-energy neutrons is correlated with the iron and titanium abundances in the surface [2]. Besides, it has even been determined that the fast neutron flux is 3 times more sensitive to FeO than to TiO_2 [2]. The possibility to obtain geochemical information from planetary fast neutrons was established by numerical simulations, which reveal the strong impact of iron and titanium on the integrated neutron flux between 500 keV and 8 MeV [3]. These last calculations show also the influence of calcium, silicon and aluminum [4]. However, the effects of these chemical elements in the fast energy range seem to be energy dependant. The instrumental response must also be taken into account to understand the geochemical information included in fast neutron data. Knowing the influence of each element and the efficiency of the detector, we can predict the chemical knowledge enclosed in the Lunar Prospector fast neutron data.

Planetary Neutron Physics and its Simulation: Whenever a planetary atmosphere is thin, many neutrons are generated by nuclear interactions between high-energy galactic cosmic rays and the nuclei of surface material. The distribution of neutrons, which escape to space depends on the composition of the upper surface layer [5]. Indeed, the fast neutron spectrum (energy between 100 keV and 10 MeV) reflects both the production of the neutrons and their subsequent moderation in surface material.

Computer simulations are used to evaluate the creation of neutrons and to predict their leakage spectra after transport and moderation processes in the soil. This numerical simulation makes use of the GEANT code library [6].

In the fast energy range of Lunar Prospector's Neutron Spectrometer [0.5 to 8 MeV], a linear relation between the integrated flux and the abundances of chemical elements was assumed as:

$$J = \Sigma \, \alpha \, [w] \qquad (1)$$

Where J is the integrated neutron flux between 500 keV and 8 MeV ($neutron.cm^{-2}.s^{-1}$), α are proportional coefficients for each chemical element ($neutron.cm^{-2}.s^{-1}.weight\ fraction^{-1}$) and w are the weight fractions of the elements.

Using several typical lunar compositions, a set of α coefficients was calculated to fit the formula 1 all over the Moon [4]. Each coefficient represents the number of leakage neutrons, which could be associated with the corresponding chemical element.

As said before, iron and titanium have the highest coefficients, and so it is possible to identify the presence of iron and titanium with fast neutrons as shown in the measurements [2]. Although the silicon coefficient is also large, silicon is uniformly distributed over the lunar surface and so will not contribute to variations in fast neutron counting rates. Sodium and magnesium abundances (under1% and 5% respectively in weight percent [7]) and their α coefficients are low so their abundance variations should also be hard to detect with the fast neutrons. Nevertheless, aluminum and calcium are both abundant enough in highlands (13% and 10% respectively in weight percent) and have sufficiently high coefficients to be visible in the fast neutron leakage spectra.

Comparison of Predicted Versus Measured Fast Neutrons: Using these coefficients, FeO and TiO_2 abundances measured with Clementine spectral reflectance data (CSR) [8] and correlations between aluminum, calcium and iron abundances [7], we have estimated the predicted flux.

These fluxes are compared with measured fast neutron fluxes in Figure 1. The correlation is better for maria than for highlands: actually, predicted flux seems to be too high in highlands which have a low content in iron and titanium and a high content in aluminum and calcium. This suggests that the aluminum and calcium calculated coefficients may be too high.

Efficiency Effect: This lack of correlation between predicted and measured fast neutrons in the highlands may be due to the efficiency of the instrument. Indeed, the response function of the instrument decreases as E^{-1} when the energy E increases from 0.5 to 8 MeV [9].

Dividing the previous simulated spectra by the energy, we are able to calculate a new set of α coefficients, which take into account the efficiency of the detector. These new coefficients are given in Table 1.

When we compare old and new coefficients, the new ones are smaller and separate into two categories: (1) iron, titanium and calcium coefficients are quite high (between 1.6 and 2.0 $neutrons.cm^{-2}.s^{-1}.weight\ fraction^{-1}$); (2) oxygen, sodium, magnesium, aluminum and silicon (0.6-0.9 neutrons.cm^{-2}.s^{-1}.weight fraction^{-1}) have lower coefficient values. However, the range of variation has decreased and it would be more difficult to separate the effect of each element with this kind of instrumentation.

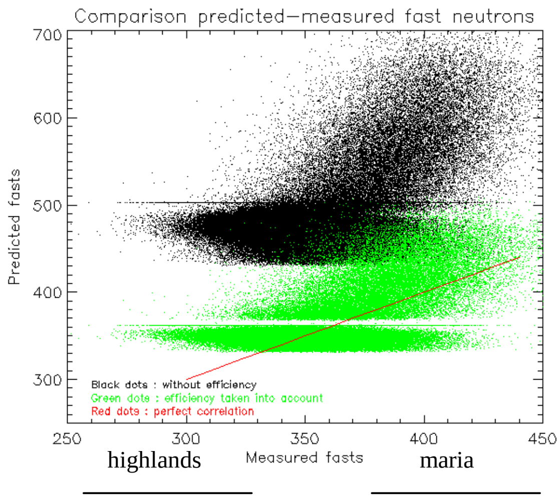

Figure 1. Lunar fast neutron data predicted vs measured. The predicted flux is calculated with α coefficients, CSR FeO and TiO_2 abundances and models for CaO and Al_2O_3. The measured flux is from Lunar Prospector. The black dots use the first set of α coefficients and the green dots use the new coefficients, taking efficiency into account. The red line is a perfect correlation between predicted and measured.

The new predicted flux, taking efficiency into account, has been plotted using green points in Figure 1. As expected, the lack of correlation between predicted and measured fast neutrons is reduced: the new coefficients give a better understanding of the measurements. According to Table 1, it will be possible to get geochemical information about iron, titanium and calcium from the fast neutron data of Lunar Prospector. However, the information on aluminum included in leakage flux is reduced when detector efficiency is included in the calculation. This is consistent with the idea that aluminum does not contribute importantly at the lowest energies of the fast energy spectrum. According to the simulations, the aluminum effect on the spectrum seems to be between 2 and 3 MeV.

element	α coefficients * without efficiency	α coefficients * with efficiency
O	0.165	0.611
Na	1.28	0.661
Mg	1.68	0.833
Al	2.09	0.952
Si	2.26	0.855
Ca	1.75	1.61
Ti	3.02	1.70
Fe	2.81	2.01

* neutron.cm^{-2}.s^{-1}.weight fraction^{-1}

Table 1. Coefficients for the Calculation of the Integrated Flux of Fast Neutrons with a Linear Combination of Weight Fractions, first without considering the Efficiency of the Instrument and second taking it into account.

Conclusion: This work demonstrates the ability of Lunar Prospector's fast Neutron Spectrometer to measure and map the abundances of iron, titanium and probably calcium at the Moon surface. The fast neutron flux also includes information on the abundances of aluminum, magnesium and sodium; at present their detections are more difficult because their effects are low or occur above 2 MeV.

The study of fast neutron fluxes is also of great importance because these neutrons are the source of lower energy neutrons and of the inelastic neutron scatter gamma-rays, which contain more geochemical information.

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