IDENTIFICATION OF LUNAR ROCK TYPES. A. A. Berezhnoy[1,2], N. Hasebe[1], M. Kobayashi[1], G. Michael[3] and N. Yamashita[1] [1]Advanced Research Institute for Science and Engineering, Waseda University, Tokyo, Japan [2]Sternberg Astronomical Institute, Moscow, Russia [3]German Aerospace Center, Institute for planetary research, Berlin, Germany

Abstract: The quality of Lunar Prospector measurements of elemental composition of the lunar surface is checked by comparison between remote sensing and returned sample collection data sets. In western maria Si content is underestimated, but Mg content is overestimated by Lunar Prospector. Petrologic mapping of the Moon with usage of Lunar Prospector Mg, Al, Fe abundances is performed. Relative content of end-members as mare basalts, ferroan anorthosites, Mg-rich rocks is estimated. Special technique for identification of unusual rock types is developed by analysis of distances of Lunar Prospector pixels from end-member plane.

Introduction: Elemental mapping of the lunar surface is very useful technique for study of petrologic provinces on the Moon, for search for chemical anomalies sites and ancient cryptomaria, and for identification of lunar rock types. Global mapping of Th and Fe content on the Moon was conducted using low resolution Lunar Prospector gamma ray spectra [1]. Preliminary data about abundances of other elements as O, Si, Mg, Ca, Al, K, U, and Ti are presented also [2].

In this work we analyze the quality of Lunar Prospector gamma ray spectrometer data comparing Lunar Prospector measurements with the results of investigations of elemental composition of returned samples. Other our goal is petrologic mapping of the Moon.

Quality of Lunar Prospector elemental data: Let us estimate the quality of Lunar Prospector gamma ray spectrometer data. One of the possible ways is comparison of elemental composition of Apollo and Luna landing sites measured by Lunar Prospector and by analysis of returned samples. Bulk composition of returned samples sites is taken from [3]. Correlation coefficients between both data sets are maximal for Ti and Fe data. For other elements with weaker gamma ray lines agreement between both data sets is not so good. Correlation coefficients are positive for Mg, Ca, Al and negative for Si. Si content in Th-rich western maria is lower on 5-10 wt% according to Lunar Prospector results than that measured in returned samples. Underestimation of Si content leads to overestimation of Mg content on some weight percents in west maria. This fact can be explained by incorrect calculations of partial intensity of 2754 keV Si and Mg gamma ray lines due to interference with 2615 keV Th line. Let us note that Al has gamma ray line at 2754 keV also. However, Lunar Prospector measured Al content in Th-rich regions correctly, because Al content can be determined with use of other Al gamma ray lines.

Petrology of the Moon: Using Apollo gamma ray and X-ray spectrometers data such as Fe and Th content and Al/Si, Mg/Si ratios, it was proposed that all observed elemental abundances on the Moon can be explained by presence of three end member rock types (ferroan anorthosite, mare basalts, KREEP basalts and Mg-rich rocks) [4]. In our work we choose Mg-Al and Mg-Fe diagrams and mare basalts, ferroan anorthosites, and Mg-rich rocks as end members. Let us assume that Mg-rich rocks have the same composition as troctolites. This assumption leads to underestimation of Mg-rich rocks content, because the difference between troctolites and other end-members composition is significantly larger than that for other Mg-rich rocks as norites and gabbronorites. The elemental composition of end-members is taken from [5]. The relative abundances of end members are plotted in ternary space for each pixel on the lunar surface. Primary colors red, blue, and green are assigned for mare basalts, ferroan anorthosites, and Mg-suite rocks, respectively (see Fig. 1). The ternary space defined by these points is represented by the mixture of these primary colors.

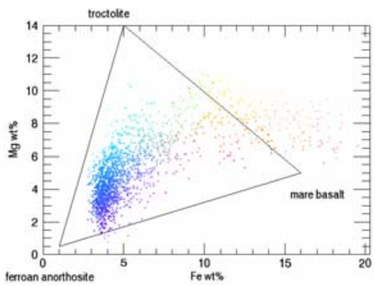

Fig. 1. Scattergram shows Lunar Prospector gamma-ray spectrometer data for 5 degree squares in Mg-Fe compositional space.

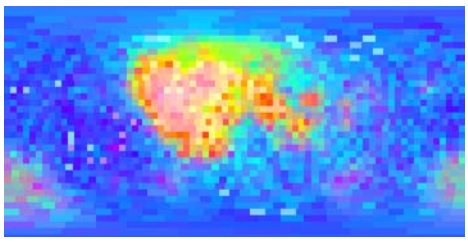

Fig. 2. Petrologic map of the Moon based on Fe and Mg Lunar Prospector data.

Majority of the lunar surface belongs to highlands with ferroan anorthosite as dominant rock type with small amounts of other end members (see Fig. 2). Mg-rich rocks are located in some cryptomaria such as Copernicus cryptomare and the Balmer basin, in the Mare Frigoris and the Gartner-Atlas regions, at the edges of big maria, and east from Mare Serenitatis. The presence of mare basalts in highlands is detected in the majority of known cryptomaria: the Lomonosov-Fleming basin, the Schillerd-Schickard and Mendel-Rydberg regions, and in Mare Orientale. Our results agree with petrologic mapping of the Moon conducted by [6]. This fact demonstrates the suitability of our approach for representing of lunar petrologic provinces.

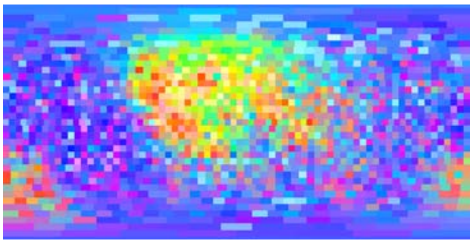

Fig. 3. Petrologic map of the Moon based on Al and Mg Lunar Prospector data.

It is possible to search for rare rock types, based on Lunar Prospector data. The biggest pyroclastic deposit region at the Aristarchus plateau is distinguished from surrounding places by unusual high Mg/Al ratio, and high Th and Ti content. Other pyroclastic deposits are too small for detection at 150 km spatial resolution. While we choose troctolites as a third end-member, there are no regions on the Moon with elemental composition typical for troctolites. But other Mg-rich rock types were detected. Gabbronorites are located at the edges of eastern maria. It is difficult to distinguish norites, because norites have the same elemental composition as the mixture of ferroan anorthosites and troctolites. For better identification of lunar rock types near infrared spectra of the lunar surface must be analyzed together with gamma-ray data.

If the three end-member hypothesis is correct, the colors of all pixels on both the Mg-Fe (see Fig. 2) and Mg-Al (see Fig. 3) maps should be the same. However, there are more red and green pixels on Mg-Al map than on Mg-Fe map. This fact can be explained by existence of errors in elemental data and by the presence of rocks with different elemental composition from the end-member rocks. The degree of the difference between end-members and measured elemental composition is proportional to the distance of pixels from three end member plane. Negative ρ values mean that Fe, Mg, or Al content in Lunar Prospector pixel is higher than that in a mixture of end-member rocks, while positive ρ values mean underestimation of Fe, Mg, or Al content in comparison with end-members.

Map of ρ values on the Moon is useful for improvement of three end-member model. Addition of fourth end-member is required, because Lunar Prospector data do not lie on the three end-member plane in Mg-Al-Fe compositional space. The biggest region with negative ρ values is located in Th-rich western maria. Addition of fourth end-member with elemental composition typical for western maria is desirable for better representation of Th-rich region. Lunar Prospector measured the following elemental composition of western maria: 15 wt% Fe, 7 wt% Mg, 8 wt% Al. The best candidates for fourth end-member are KREEP basalts, which are abundant in Th-rich western maria. However, Lunar Prospector elemental composition of western maria is different from composition of KREEP basalts (9 wt% Fe, 4 wt% Mg, 8 wt% Al), norites and mare basalts. This means that the appearance of this region on ρ values map can be explained by incorrect estimation of Mg content. Thus, the quality of Lunar Prospector data is not suitable for addition of fourth end-member with use of Mg-Al-Fe petrologic technique.

Pixels with maximal positive ρ values showed as violet pixels on Fig. 3 are located in far side highlands. These pixels have lower Al content (9-11 wt%) and higher Ca content (12-16 wt%) in comparison with surrounding places. Such Ca-rich, Al-low rocks are not presented in current lunar rock collection.

When more accurate elemental data will be available it will be possible to use Mg-Al-Fe and Mg-Th-Fe petrologic techniques for determination of content of four end-member rock types (ferroan anorthosites, mare basalts, KREEP basalts, Mg-rich rocks) on the lunar surface.

Conclusions: Comparison between elemental composition of landing sites measured by Lunar Prospector and composition of returned samples is a good technique for estimation of the quality of Lunar Prospector gamma-ray spectrometer data. Si data are not suitable for data analysis. Mg content is overestimated by Lunar Prospector, especially in western maria. Petrologic mapping of the Moon, using Fe, Mg, and Al content, is powerful method for estimation of abundances of ferroan anorthosites, mare basalts, and Mg-rich rocks on the lunar surface. Ca-rich, Al-low small-area anomalies are detected in far side highlands. This petrologic technique can be used for analysis of future SELENE gamma ray spectrometer data.

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