LUNAR METEORITE NORTHEAST AFRICA 003-A: MICROSTRUCTURES, CRYSTALLIZATION MODELING AND POSSIBLE LUNAR SOURCE AREAS.

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Introduction: The Apollo and Luna rocks and regolith samples are coming from the known locations on the Moon, but these rocks represent only small part of the lunar surface. Samples from other unsampled parts of the Moon are represented by increasing group of lunar meteorites. These meteorites come from unknown locations on the Moon and were ejected by meteoroid impacts. Many of these meteorites have features different from Apollo samples and they were probably derived from so far unexplored areas of the Moon.

Northeast Africa 003 (NEA 003) is a mare basalt and basaltic breccia [1]. The lithology we designate Northeast Africa 003-A (NEA 003-A), which comprises the main portion (~75 vol.%) of the meteorite, is an unbrecciated mare basalt. Adjacent part, Northeast Africa 003-B (NEA 003-B), is a basaltic breccia (~25 vol%) [2].

Petrography, Mineral and Bulk Chemical Composition - Summary: NEA 003-A is a coarse-grained low-Ti olivine-rich basalt. The rock is showing porphyritic texture of olivine (Fo$_{73-19}$), zoned pyroxene (En$_{5-71}$Wo$_{6-38}$) and plagioclase (An$_{84-92}$),. Undulatory to mosaic extinction of olivine and pyroxene crystals indicate that these crystals have been deformed and presence of the numerous crack and fractures indicate the intensive shock processes. All plagioclase is totally converted to maskelynite. High Mg# (52.6) together with low concentration of Al_2O_3, CaO, Na_2O and K_2O of this sample can be an indicator of primitive character of the source magma and presence of cumulate olivine. The presence of cumulate olivine is in good agreement with petrographic observation, olivine mineral chemistry and modal composition of NEA 003-A with high abundance of Mg-Fe enriched phases and low plagioclase content.

NEA 003-A has the lowest and flattest chondrite-normalized REE pattern among all known mare-basalt meteorites. Concentrations of incompatible trace elements of NEA 003-A are very low in comparison with majority of other lunar basalts. The only known lunar basalts with comparably low ITE concentrations are the VLT basalts of Apollo 17 and Luna 24.

Detail petrography, mineral and bulk chemistry have been previously described in [1].

Microstructures: Microstructure relations among NEA 003-A mineral phases can provide crucial information for understanding the magma evolution and crystallization with the purpose to define the mode of magma flow and degree of shock metamorphism. For this study we used the method of image analysis and electron backscatter difraction (EBSD). EBSD data for determining the crystallographic preffered orientation (CPO) of olivine, pyroxene and ilmenite were collected. The data were collected in manual mode for quantification of inter-mineral angular relations and in linescan automatic mode for specification of misorientations of selected mineral grains.

Image processing collected with optical microscope show a homogenous distribution of minerals within the sample with no preferred orientation of grains. Misorientations of selected olivine, pyroxene and ilmenite grains were studied in two orthogonal misorientation profiles for each grain. Acquired misorientation data (Fig. 1) reveal a small angular deviations within the internal structure of grains which could be ascribed to the shock process.

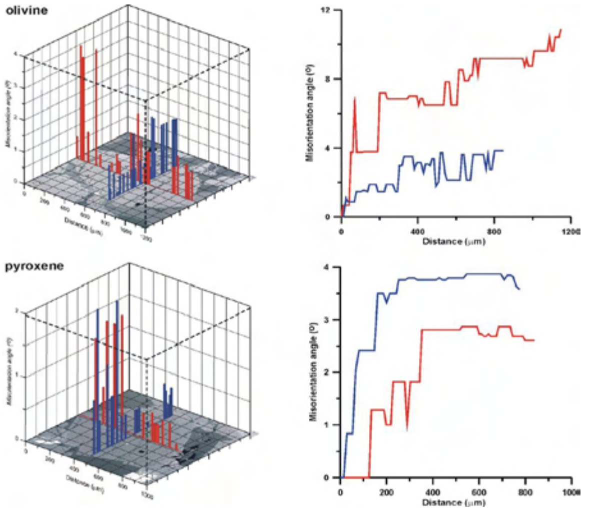

Figure 1.: (left) Orthogonal misorientation profiles for selected grains of olivine and pyroxene. 3D plots show change in misorientation along profile relative to the previous measurement. (right) Distance (µm) versus misorientation angle (°) plot show change in misorientation along profile relative to the first measurement.

CPO data for olivine, pyroxene and ilmenite show no significant preferred orientation typical for many volcanic rock from Earth. This fact together with coarse grained texture of the sample could be an evidence for relatively stable magma crystallization conditions and obviously low influence of a magma flow. CPO data for each phase are represented in stereographic projection of main crystalographic plains in Figure 2.

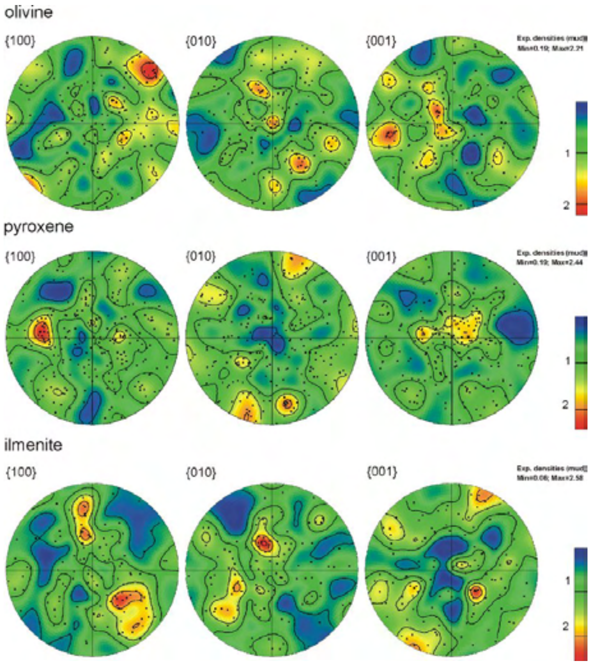

Figure 2.: CPO data for olivine (189 points), pyroxene (251 points) and ilmenite (124 points) are presented in stereographic projection of main crystalographic plains on lower hemisphere.

Crystallization Modeling: For calculation of Fo content of olivine in equilibrium with a whole rock Mg# [3] we used the TiO_2 calibrated Kd [4], where NEA 003-A has a Kd=0,33. Calculated Fo content of olivine for NEA 003-A Mg#=52,6 is about Fo_{77}. However, the highest measured Fo content in the cores of the earliest formed NEA 003-A olivines (Fo_{72}) is lower than the calculated Fo content. This fact together with unusually high modal portion of olivine and some above mentioned geochemical features indicate the presence of cumulate olivine and his accumulation in the parental magma.

Before crystallization modeling we had calculated the portion of cumulate olivine (equiliblium Fo content=measured Fo content). This olivine portion (10%) was removed and the bulk composition of NEA 003-A was recalculated. The recalculated bulk-rock composition was modeled using the PELE software based on the algorithms and database of [5,6]

The results of low-pressure (1bar) models of crystallization sequence for equilibrium and fractional crystallization provide good and consistent datasets. Modeling started with a liquidus temperature of 1327 ^{o}C and oxygen fugacity equivalent to Iron-Wustite buffer. Comparing both models, fractional crystallization provides better results which with conspicuous agreement between predicted and observed compositional ranges of majority of mineral phases. The low-presure model of fractional crystallization for recalculated NEA 003-A bulk-composition predict that chromian-spinel crystallized as a first phase from a cooling liquid at 1327 ^{o}C, followed by olivine (Fo_{73}) at 1241 ^{o}C, pigeonite (En_{71}, Wo_{6}) at 1171 ^{o}C, clinopyroxene (En_{63}, Wo_{26}) at 1130 ^{o}C and plagioclase (An_{87}) at 1148 ^{o}C.

Predicted and observed compositional ranges of mineral phases are very similar, excluding the plagioclase where bigger difference can be registered (observed $An_{84\text{-}92}$, predicted $An_{86\text{-}88}$). This difference is possible subsequence of the shock processes and complete conversion of plagioclase to maskelynite.

Possible lunar source areas: Using global remote sensing data from Lunar Prospector gamma ray spectrometer [7] and from Clementine spectral reflectance [8], these data can indicate several possible source areas for NEA 003 A. Most recently determined Ar/Ar age for NEA 003-A described in [9] is 2.377±0.04 Ga (2σ). NEA 003-A thus represents a very young lunar low-Ti olivine rich basalt. In respect to the young age of the meteorite we can specify the possible source areas: Oceanus Procellarum, Mare Imbrium and central (younger) part of Mare Serenitatis, where the longer active volcanic activity is considered [10].

References: [1] Haloda J. et al. (2006) *LPSC XXXVII*, abst. #2269; [2] Haloda J., et al. (2006) *LPSC XXXVII*, abst. #2270; [3] Roeder P. L. et al. (1970) *Contrib. Mineral. Petrol.* 29, 275-289; [4] Delano J. W. et al. (1980) *Proc. Lunar Sci. Conf.* 11, 251-288; [5] Ghioroso M. S. (1985) *Contrib. Mineral. Petrol.* 90, 107-120; [6] Ghioroso M. S. et al. (1994) *Contrib. Mineral. Petrol.* 119, 197-212; [7] Lawrence D. J. et al. (2000) *J. Geophys Res.* 105, 20, 307-20,331; [8] Giguere T. et al. (2000) *Meteoritics and Planetary Science* 35, 193-200; [9] Fernandes V. A. et al. (2007) *LPSC XXXVIII*, in this volume; [10] Hiesinger H. et al. (1998) *LPSC XXIX*, abs. #1243.