DHOFAR 301: EVIDENCE FOR STRONG REDUCTION IN LUNAR HIGHLAND ROCKS. M. A. Nazarov[1], S. I. Demidova[1], F. Brandstaetter[2], Th. Ntaflos[3]; [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Kosygin St. 19, Moscow 119991, Russia (nazarov@geokhi.ru), [2]Natural History Museum, A-1010 Vienna, Austria, [3]Department of Lithospheric Research, University of Vienna, A-1090 Vienna, Austria.

Introduction: The Dhofar 301 lunar feldspatic meteorite is obviously paired with Dhofar 025 that represents the main mass of the meteorite shower [1-3]. During a preliminary study of Dhofar 301 [1] a lithic clast (301-1r) of a highly reduced Mg-rich rock was found. In this paper we report on a detailed investigation of the clast, which contains practically Fe-free pyroxenes and shows evidence for reduction and mobilization of Fe, Cr and Mn in the lunar environment.

Results: The clast (#301-1r) has a size of 0.4x0.5 mm and consists of 80% of plagioclase and 20% of pyroxenes (Fig. 1). Both clino- and orthopyroxenes are present and orthopyroxene is approximately 2 times more abundant. Pyroxene grains are up to 50x100 µm in size. Accessories are silica and metal. Ca-carbonate and Fe hydroxides of terrestrial origin are present too. In terms of mineral composition the rock can be classified as a gabbro-noritic anorthosite. Pyroxenes are practically Fe-free. Their FeO content is in the range of 0.06-2.44 wt%. However, the majority of pyroxene grains contains <0.2 wt% FeO. The higher FeO concentrations certainly are due to the presence of tiny submicron metal inclusions which are located mostly along cracks in pyroxene grains. *Enstatite* has Wo 0.9-2.8 and contains 0.7-2.7 wt% Al_2O_3 (mean is 1.7), 0.26-0.48 wt% TiO_2, <0.1 wt% MnO, and <0.14 wt% Cr_2O_3. *Clinopyroxene* (Wo 41.5-43.7) is poorer in Ca than diopside and contains 1.45-2.73 wt% Al_2O_3 (mean is 2.13), 0.9-1.7 wt% TiO_2, <0.1 wt% MnO, and <0.13 wt% Cr_2O_3. As compared to pyroxenes of lunar feldspatic meteorites, the pyroxenes of the 301-1r fragment are very depleted in MnO and Cr_2O_3 (Fig. 2). However, the FeO/MnO wt% ratio of the 301-1r pyroxenes varies from 1 to 4 and much lower than that (~60) of lunar meteorite pyroxenes [4]. *Feldspar* is An 90.4-93.6 (the mean is An 92.3), Ab 6.4-9.1 (mean is Ab 7.4). FeO content of the feldspar is <0.18 wt% (mean is 0.09) and lower than its MgO content (0.27-0.43 wt%, mean is 0.34). The FeO/MgO ratio of the plagioclases is very low when compared to that of feldspars of the Dho 025, 301 and 304 meteorites (Fig. 3). One metal grain that was analyzed in the rock has meteoritic metal composition (7.04 wt% Ni; 0.36 wt% Co) but is enriched in P (0.77 wt%).

Discussion: The prominent characteristic of the 301-1r rock is the practically FeO-free compositions of the pyroxenes. Even feldspar has very low Fe/Mg ratio. The FeO depletion is accompanied by a strong depletion in Cr and Mn of the pyroxenes.

The 301-1r clast is very different from meteoritic associations with high MG#, e.g., enstatite chondrites which are rich in FeNi metal, sulfides and contain sodic feldspar. Such rocks have never been documented in lunar samples and lunar meteorites. However, in terms of mineral modes and An content of plagioclase the 301-1r rock is not distinguishable from lunar highland anorthositic lithologies. Thus, this rock should be of lunar (but not extra-lunar) origin.

FeO-free, mafic silicates cannot be produced by usual processes of magmatic fractionation. Therefore, we suggest strong reduction caused by fluid metasomatism to explain the unusual mineral chemistry. The presence of the tiny metal inclusions along cracks in the pyroxene grains strongly supports that explanation. Such reduction processes has been suggested for lunar environment [5]. The absence of sulfides and water-bearing phases in the rock means that the best reducing agent should be a CO gas but not H2 or S-bearing species. CO can reduce FeO from pyroxenes:

$$FeSiO_3 + CO = Fe + SiO_2 + CO_2$$

Rare silica grains are indeed present in the 301-r rock. The reduction also could produce carbonyl species:

$$Fe + 5CO = Fe(CO)_5$$

The very mobile species are known also for Cr and Mn [e.g., 5]. It can be suggested, therefore, that some amount of Fe, Cr and Mn could be removed from a precursor rock as carbonyl compounds.

Obviously, FeO of the pyroxenes was totally reduced. The reduced amount of Cr and Mn can be estimated based on lunar mineral chemistry. The 301-1r clast contains feldspar which is higher in Na relative to that of ferroan anorthosites and, hence, a precursor lithology of the 301-1r clast should belong to the high Mg (HMS) rock suite. The An-MG# correlation in the suite [6] and the 301-1r feldspar composition give MG# of the precursor pyroxene of about 77 mol%. It corresponds to 15 wt% FeO of the precursor orthopyroxene and ~3 wt% FeO of the precursor rock. Then, at the lunar pyroxene FeO/MnO ratio of ~60 [4] the MnO content of the initial orthopyroxene should be 0.25 wt% and, therefore, >60% Mn were reduced from the pyroxene grains. The Cr reduction from the grains can be evaluated from the Al-Cr correlation in lunar pyroxenes and should be > 75%.

An estimate of a possible Fe loss from the 301-1r rock can be obtained on the basis of the modal content of the tiny metal inclusions in the pyroxene grains. The modal content corresponds to 2-3 wt% FeO which resides now in the pyroxenes as tiny metal grains. This implies that about 80% of Fe could be mobilized and removed as carbonyl species from the whole rock if the precursor pyroxene had 15 wt.% of FeO.

Reducing reactions have been documented in enstatite chondrites [e.g., 7], ureilites [e.g., 8], a lodranite, [9] a mesosiderite [10], a howardite [11], and the 67016 lunar breccia [12]. However these reports describe mostly Fe reduction from olivine by S-bearing species whereas strong reduction of Fe, Cr and Mn from pyroxene by CO gas has never been reported. Thus, the 301-1r rock is an unique case.

The presence of Fe,Ni metal of meteoritic composition in the 301-1r rock suggests that this rock is a metabreccia of impact origin. Probably the breccia was totally recrystallized and reduced by CO gas in a hot ejecta blanket. The occurrence of the rock allows us to suggest that such reduction processes could be active during the formation of lunar impact deposits and affect major and minor element chemistry of lunar impactites.

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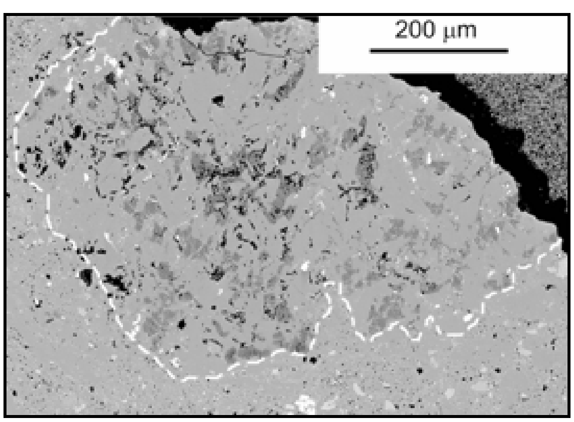

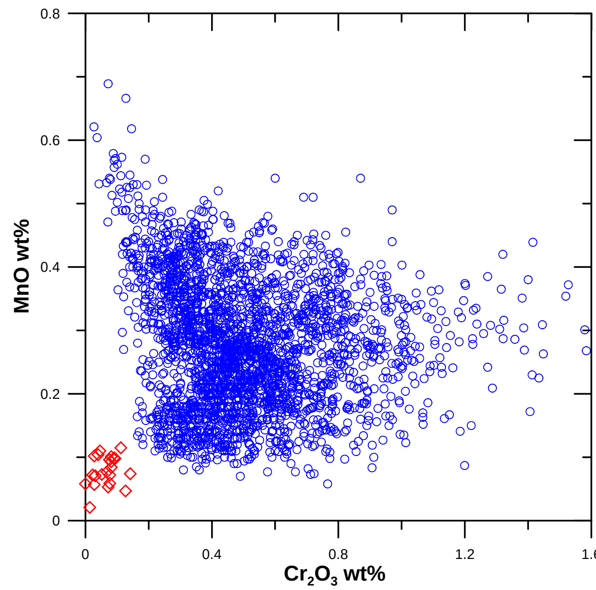

Fig. 2. MnO vs. Cr_2O_3 in lunar meteorite pyroxenes with MG# > 40 mol.%. The red diamonds are pyroxenes of clast 301-1r. Only our data are shown.

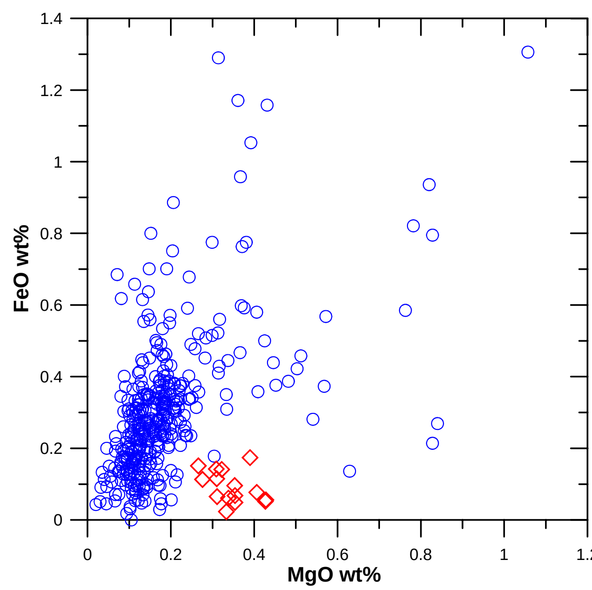

Fig. 3. FeO vs. MgO in plagioclases of Dho 025, 301 and 304. The red diamonds are pyroxenes of clast 301-1r. Only our data are shown.

Fig.1 Clast 301-1r in the Dho 301 lunar meteorite. Pyroxenes are dark grey. Bright spotsare mainly Fe-hydroxides and rare FeNi metal grains. BSE image.