ENIGMATIC CATHODOLUMINESCENT GLASSES IN THE DHOFAR 025 LUNAR HIGHLAND METEORITE: EVIDENCE FOR IMPACT ORIGIN OF SPINEL ANORTHOSITES. S. I. Demidova[1], M. A. Nazarov[1], K. M. Ryazantsev[1], M. O. Anosova[1], F. Brandstätter[2], and Th. Ntaflos[3] [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Kosygin St. 19, Moscow 119991, Russia, demidova.si@yandex.ru; [2]Naturhistorisches Museum, Burgring 7, 1010 Vienna, Austria; [3]Department für Lithosphärenforschung, Universität Wien, Althanstrasse 14, 1090 Wien, Austria.

Introduction: Dhofar 025 (Dho 025) is a lunar highland meteorite with no mineralogical evidence for a KREEP presence. However the rock is characterized by highest REE contents among the highland meteorites [1]. Here we report on occurrence of cathodoluminescent (CL) glasses in Dho 025. The glasses have spinel-plagioclase composition similar to that of lunar spinel anorthosites. Mostly they are enriched in Ti, REEs and other incompatible elements.

Methods: A polished thick section of the Dho 025 feldspathic breccia was studied using optical microscopy and scanning electron microscopy (JEOL JSM-6610LV with Gatan MonoCL4 detector). Chemical composition of the mineral phases was measured using JEOL JXA-8530F and Cameca SX100 microprobes in Vienna. A laser ablation system UP-213 (New Wave) attached to inductively coupled plasma-mass spectrometer Element-XR (Moscow) was used to measure trace and some major elements. Laser pulse frequency of 4 Hz and beam diameter of 30 µm were used for the analyses. Data reduction was performed with Glitter software program [2]. Analyses were calibrated against the NIST 610 external standard and EMPA measured Al content of each glass as an internal standard.

Results: Dho 025 is an anorthositic impact melt breccia containing mineral and lithic fragments [3]. Lithic clasts (up to 1.5 mm in size) of anorthositic, noritic, gabbro-noritic and troctolitic composition are common. Rare clasts of VLT basalts were found as well. Most of the lithic clasts are impact melt breccias and poorly crystalline impact melts. However, granulitic and cataclastic rocks are present, too. Coarse-grained lithic clasts with a possibly primary texture are rare. Mineral fragments are similar in composition to those of lithic clasts. However, there is a population of rather coarse-zoned fragments of pleonaste (MG# 76-92), Mg-rich olivine (MG# 76-90), and minor Mg-rich low-Ca pyroxene (MG# 78-89).

The meteorite contains an extremely fine-grained partly recrystallized glassy matrix. Numerous small mineral fragments and schlieren objects are common in the matrix. One rounded glass fragment (160x170 µm) enriched in Na and K was found. The matrix makes up 30-40% of the meteorite.

The CL objects are sized from 10x10 to 70x120 µm and have an isometric or irregular shape (Fig.1a-d). In some parts they replicate the schlieren texture of the matrix. The glasses show a bluish CL signal of varying intensity unevenly distributed in the objects. In the studied section 17 such objects were recognized. The boundaries of the CL glass objects with the matrix are mainly blurred but partly are sharp. As a rule the CL glasses in contrast to the matrix glass are evenly devitrified (Fig.1a). Tiny microlites (<1, rarely 3 µm) are represented by pleonaste (MG 75-78) embedded into a glass of plagioclase composition (Fig. 1d). In one CL glass object another mafic phase is present in form of microlites but its size is too small for identification.

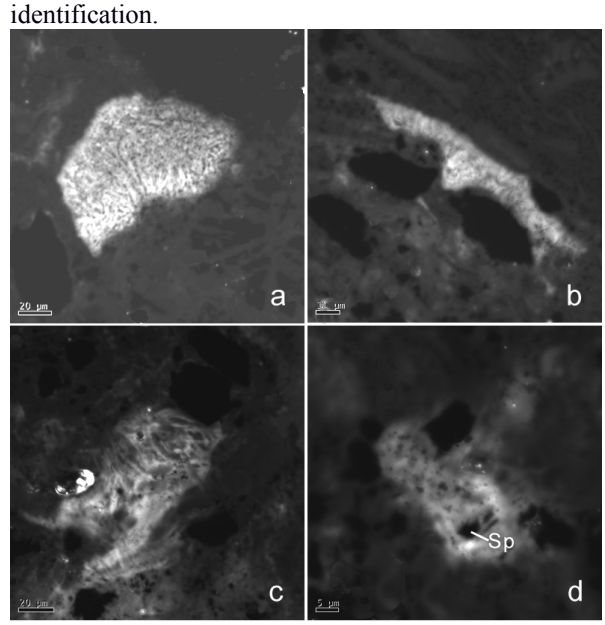

Fig.1 CL images of the Dho 025 CL glasses. Mafic phases are black.

The CL glasses vary in composition from nearly pure plagioclase to more mafic one (Table 1). The CL glasses enriched in Fe and Mg have higher MG#. Some of the CL mafic members contain up to 0.5 wt.% TiO_2. The CL glasses are certainly poorer in Na (0.1-0.3 wt.% Na_2O) and richer in Al (30-42 wt.% Al_2O_3) than Dho 025 bulk rock (0.3 and 27 respectively).

Table 1. Dho 025 CL glass compositions.

	18CL	22CL	2CL	5CL	15CL	11CL	17CL	3CL	4CL	10CL	*
SiO_2	41.8	41.2	43.6	44.3	41.8	32.3	39.9	44.3	43.1	41.0	**43.9**
Al_2O_3	29.9	31.8	33.4	31.2	30.9	40.9	37.5	32.9	36.2	31.9	**26.7**
Cr_2O_3	0.09	0.25	0.03	0.07	0.11	0.34	0.18	0.05	0.04	0.12	**0.10**
TiO_2	0.47	0.20	0.29	0.13	0.15	0.45	0.15	0.45	0.10	0.14	**0.30**
K_2O	0.04	0.02	0.04	0.04	0.01	0.01	0.01	0.03	0.01	0.02	**0.07**
CaO	16.6	17.0	19.2	18.5	17.1	14.0	18.5	18.6	20.0	16.7	**16.1**
FeO	4.73	3.44	0.97	1.92	3.92	4.63	1.61	1.84	0.41	3.03	**4.98**
MnO	0.06	0.04	0.02	-	0.05	0.09	0.03	0.03	0.01	0.06	**0.08**
Na_2O	0.11	0.10	0.27	0.29	0.08	0.08	0.08	0.30	0.05	0.10	**0.28**
MgO	5.41	5.26	0.84	3.11	4.96	6.58	1.60	1.56	0.44	6.22	**6.53**
P_2O_5	0.06	0.03	0.03	0.02	-	-	-	-	-	-	**0.08**
Total	99.3	99.4	98.7	99.6	99.6	99.7	99.9	100.4	100.6	99.7	**99.1**
MG#	67	73	61	74	69	72	64	60	65	79	**70**

* Dho 025 bulk composition

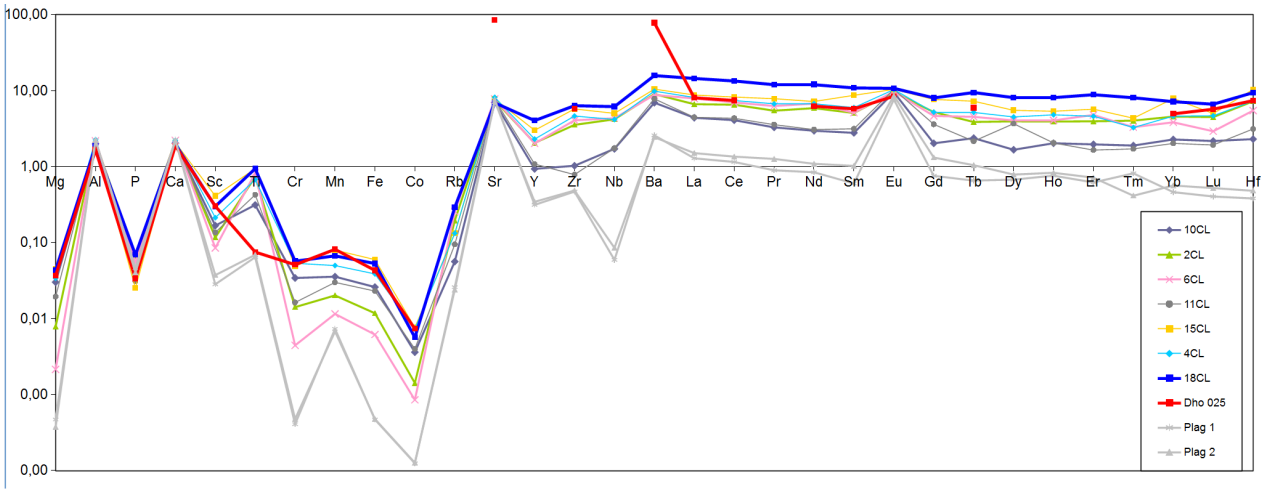

Fig. 2. CI-chondrite normalized element patterns of the CL glasses, the Dho 025 whole rock, and plagioclases.

The trace elements abundances in the CL glasses resemble those of the Dho 025 whole rock (Fig. 2). The majority of the glasses have a plagioclase-like REE pattern with a small positive Eu anomaly and an enrichment of LREEs relative to HREEs. The exception is the 18CL glass that has the most intense CL signal as well as the highest Ti, REEs (10xCI) and other incompatible elements. This glass is characterized by the absence of Eu anomaly (Fig. 2), lowest Al, highest Fe, Mg and a low MG# 67. Two other CL glasses with lower incompatible elements have composition intermediate between plagioclase and the main portion of CL glasses composition as a consequence of an admixture of surrounding plagioclase (Fig. 2).

Discussion: Mn^{2+} is the most important CL activator in lunar plagioclases [4]. In spite of the feldspathic composition of the studied glasses their CL intensity positively correlates with REE and Ti contents which therefore could be CL activators too. In addition, the intensity of the CL signal should depend on the constitution of the glass and therefore should reflect some special features of the thermal history and the nucleation kinetics of the Dho 025 CL glasses. In comparison, the Dho 025 matrix glasses which have similar trace element content but do not show strong CL signal. The absence of the CL signal may be also connected with a quenching effect of a higher Fe^{2+} amount [5]. The blurred boundaries and the variable composition indicate that the CL glasses similar to the Dho 025 matrix glasses were formed by impact melting. On the Fo-An diagram a majority of CL glass melts should crystallize spinel first (Fig. 3). In the spinel-plagioclase composition the CL glasses correspond to so-called spinel anorthosites recently discovered by remote sensing [6]. It means that the spinel anorthosites could be originated by impact mixing and melting of anorthosites with some mafic rocks, and following crystal-liquid fractionation of such impact melts. The enrichment of the CL glasses in incompatible trace elements suggests that the mafic component could be related with HMS rocks which often show such enhancement in a KREEP component. Thus the investigations supports the models [7-10] suggesting impact origin of lunar spinel anorthosites.

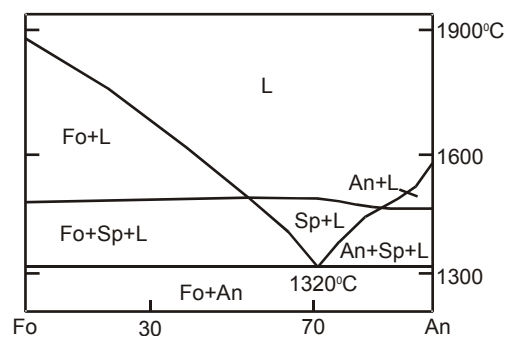

Fig. 3. Fo-An diagram [11]. The arrows show position of CL glass compositions.

Acknowledgments: This study was supported by Russian Academy of Sciences (Program №7) and RFBR grant 16-05-00695.

References: [1] Korotev R. L. (2012) *Meteoritics & Planet. Sci., 47,* 1365-1402. [2] Van Achterberg E. et al. (1999) Proc. 9th Goldschmidt Conf, 305. [3] Cahill J. T. et al. (2004) *Meteoritics & Planet. Sci., 39,* 503-529. [4] Gotze J. et al. (1999) *Amer. Mineral., 84,* 1027-1032. [5] Gotze J. and Kempe U. (2009) in *Cathodoluminescence and its applications to geosciences*, Gucsik A. (ed.), pp.1-22. [6] Pieters C. M. et al. (2011) *JGR, 116,* E00G08. [7] Pieters C. M. et al. (2014) *Amer. Mineral., 99,* 1893-1910. [8] Gross J. et al. (2014) *Amer. Mineral., 99,* 1849-1859. [9] Treiman A. H. et al. (2015) *LPS 46th,* Abstract #2518. [10] Prissel T. C. et al. (2014) *EPSL, 403,* 144-156. [11] Osborn E. F. and Tait D. B. (1952) *Amer. J. Sci., Bowen vol.,* 413.