

ORIGIN OF NATIVE SILICON AND FE-SILICIDES IN LUNAR ROCKS. M. A. Nazarov¹, S. I. Demidova¹, Th. Ntaflos², and F. Brandstaetter³ ¹Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow 119991, Kosygin St., 19, Russia, e-mail: nazarov@geokhi.ru; ²Department für Lithosphärenforschung, Universität Wien, Althanstrasse 14, 1090 Wien, Austria, ³Naturhistorisches Museum, Burgring 7, 1010 Wien, Austria.

Introduction: Native silicon and Fe-silicides were identified in two fragments from Apollo 16 regolith sample 61501,22 [1] and the Dhofar 280 lunar meteorite [2-4]. Origin of the Si-rich phases was considered as a result of (1) shock melting and reduction of impact melts [1]; (2) condensation of a silicate vapor produced by a large-scale impact [2,3] or (3) space weathering that involves melting and vaporization of lunar soils by micrometeorite impacts followed by condensation of Fe-silicides [4]. All these proposed scenarios include meteorite bombardment of the Moon and strong reduction of impact melts or an impact-induced vapor due to oxygen loss. In this paper we consider the scenarios in the light of new data obtained by ASEM and electron microprobe studies of Dho 280 sections.

Results: Dho 280 is a typical impact melt breccia with an abundant anorthositic impact melt. There are rare schlieren and spot objects consisting of very tiny silicon grains, droplets of Fe-silicides, and a silicate melt [2,3] (Fig. 1). In bulk composition the Si-rich objects are very high in Si (up to 68 wt%). Minor elements (wt%) are: P (0.2-0.4), Al (<5.4), Ca (0.7-2.1), Ti (<0.09), Mn (0.07-0.4), Fe (0.5-11.3), Ni (up to 0.25), Mg (<0.7), and S (<0.5). Na, K, and Cr are very low, if present. The objects show an oxygen depletion relatively to SiO₂ [2,3]. Oxygen content was not measured but this O deficit can be estimated reducing the 100% total for feldspar, enstatite, FeSi and other minor reduced elements. Obtained so far Si/(Si+O) ratios (at.) of the objects are shown on Fig. 2 and can be interpreted in terms of mixing of Si and SiO₂ components. Significantly, the average Si/(Si+O) ratio corresponds to Si_{0.48}O, i.e., it is very close to SiO.

Some Si-rich objects contain relatively big (up to 10-20 μm) droplets of native silicon and Fe silicides which can be quantitatively analyzed (Fig. 3,4). The silicon droplets contain certainly P (0.8-1.2 wt%). Concentrations of other elements are very variable, e.g., 0.3-4.2 Fe 0.4-1.5 Al (wt%), and can be related with a presence of minute Fe-silicide grains and contamination from surrounding. Among silicides (Fig. 5) FeSi is most abundant. Hapkeite (Fe₂Si) is rather rare. We did not find FeSi₂ reported by [4] but we identified (Fe_{2.9}Ni_{0.1})₃Si_{1.1} (suessite), (Fe_{4.33}Cr_{0.67})₅(Si_{3.04}P_{0.07})_{3.11}, and (Fe_{2.89}Mn_{0.04}Cr_{0.03}Ti_{0.04})_{3.0}Si_{7.09}. The last one is close to Fe₃Si₇ preliminary identified by [1]. Phosphorus is present in all silicides (0.1-1.3 wt%). Fe₅Si₃ and Fe₃Si₇ contain usually Mn, Cr and Ti and

are very poor in Ni and Co. The latter elements occur commonly in Fe₃Si, Fe₂Si and FeSi, which are much lower in Mn, Cr and Ti.

The melt adjacent to the Si⁰-rich objects is SiO₂-rich [2,3]. It shows usually bluish opalescence and is slightly darker in BSE. There is no any oxygen deficit in the melt. In mineral norms the melt is a mixture of plagioclase and silica with a minor mafic component [2,3].

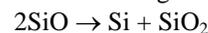
Discussion: The origin of the Si-rich phases by shock reduction of impact melts [1] seems to be impossible. Such reduction of anorthositic melt:



should lead to precipitation of Ca aluminates or at least high Al, Si-poor melts, which were not found around the Si-rich objects. On the contrary the melt surrounding the objects is SiO₂-rich. The scenario is not compatible also with the volatile element enrichments of the Si-rich objects [3,5].

Space weathering processes [4] could produce probably some native silicon because a Si⁰ signal was identified in surface layers of regolith particles [6]. However Dho 280 is not a regolith breccias. If even the rock contained a regolith component, mineralogical and chemical effects of space weathering are insignificant in bulk chemistry and mineralogy and could disappear at all during remelting. Therefore it is better to suggest that origin of the Si-rich association of Dho 280 should be related with a single large-scale impact event.

Our data show that SiO could be the main component of the Si-rich aggregates. The compositional deviation of Si-rich objects from SiO (Fig. 2) can be related with inhomogeneity of the analyzed mixture and some enrichment of the objects in SiO₂ due to oxidation of silicon. Such oxidation can explain the shift of the Si/(Si+O) modal value (0.40-0.45) from 0.5 (Fig. 2). SiO should be the dominant Si-bearing gaseous species in the impact –induced vapor of anorthositic rocks [e.g., 7]. The SiO condensate incorporated into an impact melt should give native silicon and a silica phase:



Oxidation of Si can explain the enhancement in SiO₂ of the surrounding melt and its mixing with feldspar component. Silicon can react also with FeO of the melt to form Fe-silicides. The other source of Fe is a meteorite component that is identified by enhanced Ni

and Co contents in the silicides and the SiO₂-rich melt [2,3]. Thus it can be suggested that the Si-rich phases of Dho 280 were formed by condensation of SiO from an impact-induced plume and interaction of the condensate with an anorthositic impact melt. The consideration suggests also that silicon can be easily produced by distillation of anorthositic melts and can represent economical interest to produce solar batteries directly on the Moon.

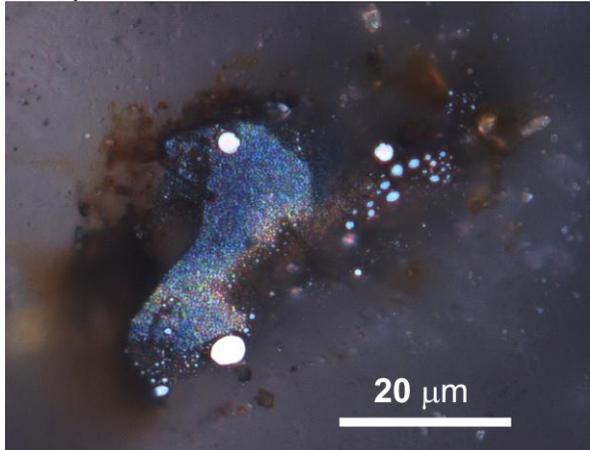


Fig. 1. A typical Si-rich object. Bright droplets are Fe-silicides. Small silicon droplets bluish-gray. Reflected light, oil immersion.

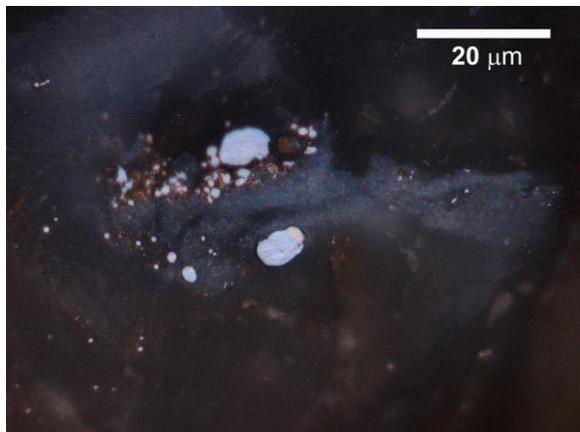


Fig. 3. Silicon droplets associate with a SiO₂-rich melt that shows bluish opalescence. Reflected light, oil immersion.

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References: [1] Spicuzza M.J. et al. (2011) *LPS XLII*, abs. #2231. [2] Nazarov M.A. et al. (2012) *LPS 43rd*, abs. #1073. [3] Nazarov M.A. et al. (2012) *Petrology*, v.20, #6, 506-519. [4] Anand M. et al. (2004) *PNAS* 101, 6847-6851. [5] Anosova M.O. et al. (2012) *LPS 43rd*, abs. #1079. [6] Dikov Yu.P. et al. (1978) *Proc. Lunar Planet. Sci. Conf.* 9th, 2111-2124. [7] Markova O.M. et al. (1986) *Geokhimiya*, no. 11, 1559-1569.

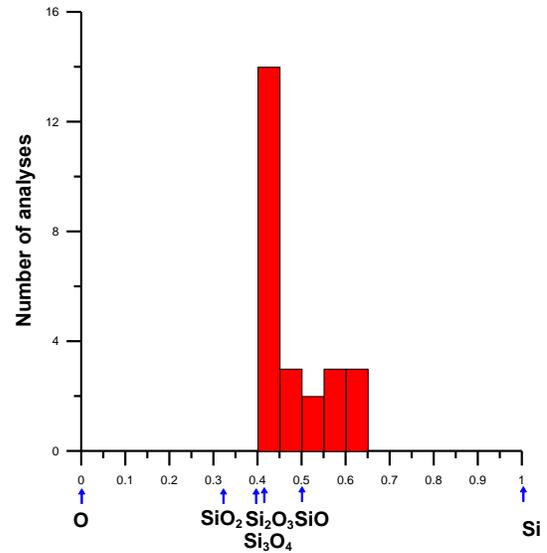


Fig. 2. Atomic Si/(Si+O) ratios of Si-rich objects.

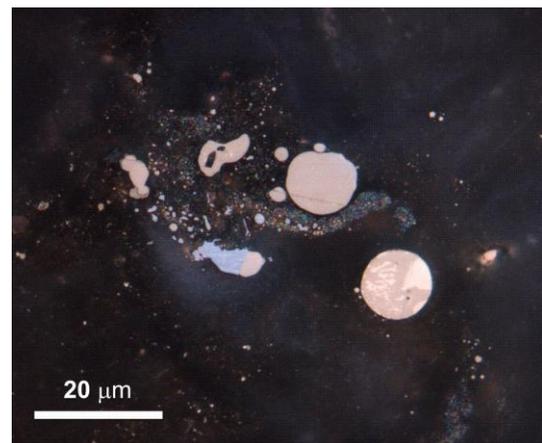


Fig. 4. Precipitation of Fe-silicides. There is an intergrowth of silicon (blue) with a Fe-silicide. Reflected light, oil immersion.

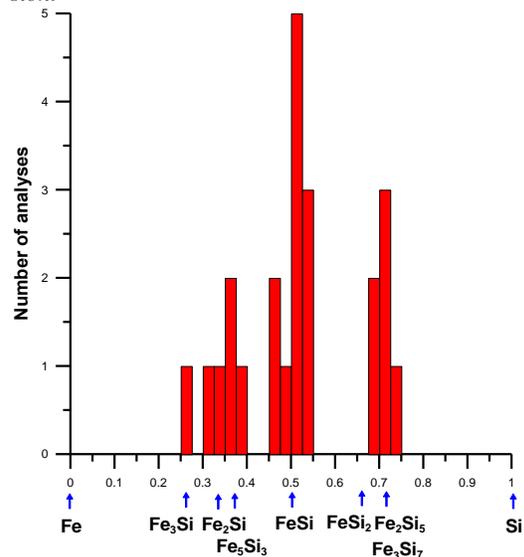


Fig. 5. Atomic Si/(Si+Fe) ratios of Fe-silicides