

**ENSTATITIC DETERMINISM OF IMPACT-INDUCED VAPORIZATION OF MAGNESIOSILICATES.**

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**Introduction:** Ultramafic and mafic minerals are the main components which could represent the material of planetesimals impacting the growing Earth during the period of accretion. Transformation of chemical composition and structure of planetesimals material during impact processing and particularly during impact vaporization can result in some global evolutionary trends of the Earth during its growth. Some early experimental works [1,2,3,4] stated congruent evaporation of forsterite giving no changes in the mineral composition. Sata et al. [5] argued for a certain disproportionation of Mg and Si between melt and vapor for forsterite and enstatite. Most of experiments on evaporation are performed at vacuum chamber pressures and temperatures which are not compatible with hundreds or thousands of bars at 4000-5000 K of an impact vaporization range. The goal of our experiments was to investigate behavior of Mg and Si during vaporization of ultramafic and mafic rocks and minerals at conditions typical for hypervelocity impact vaporization.

**Experiment:** Experiments were performed using two stage light-gas-gun (LGG) and laser pulse (LP) simulation techniques [6]. Expansion of the vapor cloud in LGG experiments was into ~10 mbar air and in case of LP experiments into 1 bar He gas. Condensates were collected on Ni and Cu foils which were placed into the path of the vapor plume expansion. Analyses of initial samples and of condensed films were performed using X-ray photoelectron spectroscopy (XPS) technique. Condensed films were etched layer by layer (with an exposition equivalent to removal of ~20 nm of consolidated silicate) by a beam of argon ions and for every layer XPS analysis was performed providing information of the cross-section of the film. XPS analyses gave both elemental chemical composition of the condensate and the distribution of elements between different bonding states.

LGG experiments were performed with olivinite and serpentine targets (Cu projectile  $v_{imp} \sim 6$  km/s). LP experiments were done with olivine, serpentine, pyroxene, enstatite, and meteorites: Tsarev (L5), Etter (L5), Allende (CV3), and Indarch (EH4).

**Experimental results:** a) *Chemical composition.* Chemical bulk composition of starting samples and related condensates are presented in Fig. 1. Compositions of condensates are regularly shifted towards higher concentration of silicon and depletion in magnesium and iron. It is worth to note that in two cases

(LP experiments with pyroxene and enstatite chondrite Indarch) the increase of Si/Mg ratio was insufficient.

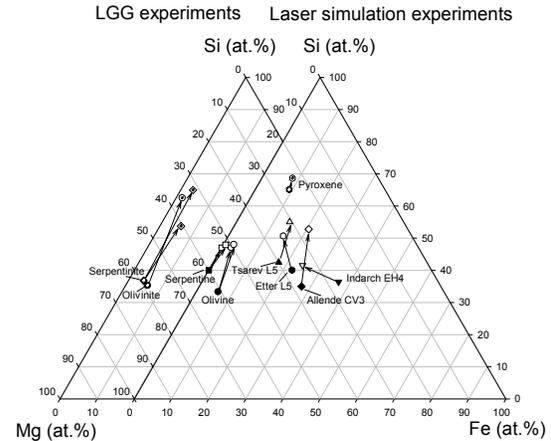


Fig. 1. Mg-Fe-Si ternary diagrams for chemical bulk compositions of starting samples (dark symbols) and their condensates (transformation is indicated by arrows). Left diagram is related to LGG experiments and right one to LP experiments.

It was also interesting to find that Mg/Si ratio for olivine, serpentine and enstatite through the thickness of the condensed films was about unity (see Fig.2).

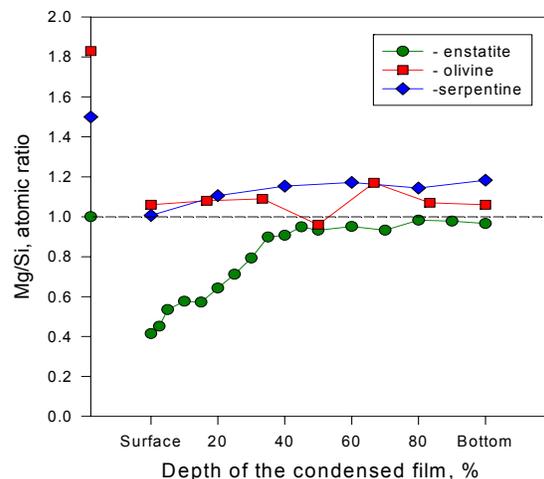


Fig. 2. Mg/Si profiles through the thickness of the condensed films which were produced during LP experiments with olivine, serpentine and enstatite. Symbols on the ordinate indicate Mg/Si ratios in starting samples.

Recalculated composition of olivine condensate corresponded to En 93-95. That indicates the shift of composition of condensate during evaporation of olivine toward enstatite.

b) *Chemical structure.* There is a uniformity of chemical structure of condensed materials which is characterized by dominant chain polymerization of silicon-oxygen tetrahedrons with sufficient portion of framework and some portion of isolated structures

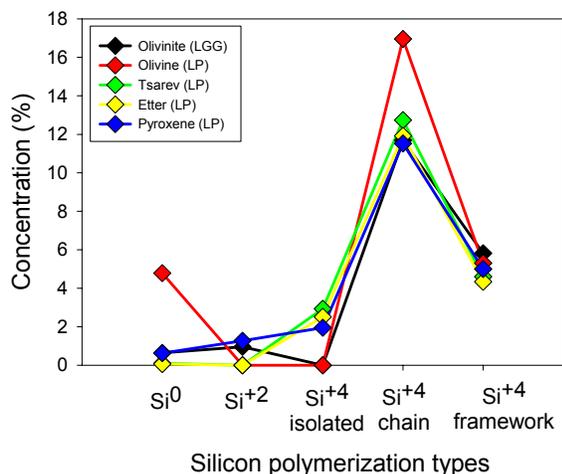


Fig. 3. Proportions between different polymerization types of Si in bulk condensates which were produced in LGG experiment with olivinite and LP experiment with olivine, pyroxene, and meteorites Tsarev and Etter.

(see Fig. 3). Condensed films also contain some quantities of reduced forms of elements ( $\text{Si}^{+2}$ ,  $\text{Si}^0$ ,  $\text{Fe}^0$ ,  $\text{Mg}^0$ ) as a result of redox processed inside a vapor cloud [7]. Condensates from LP experiment with olivine and from LGG experiment with olivinite have good structural coincidence which proves the applicability of LP method for impact-vaporization simulations. It is remarkable that both olivine and olivinite condensates are characterized by the absence of isolated silicon-oxygen tetrahedrons but preferable polymerization of tetrahedrons in chain and framework structures. Here we have a total loss of initial olivine structure and its transformation towards pyroxene type structure. Mg is redistributed between reduced, separated oxide, and bound to silicate forms. The last is the dominant one.

In case of experiments with serpentine and serpentine their condensates had mostly layered structure. About 1/3 of magnesium here was present in the form of  $\text{Mg}(\text{OH})_2$ . This effect was due to the interaction of plume components with water vapor inside the vapor cloud [8] which provided ~14 wt. % of water chemically bound to condensate.

**Discussion:** Produced condensates show compositional uniformity for Mg/Si ratio and chain polymeri-

zation. This effect works for ultramafic and mafic minerals providing in one case deep difference between starting samples and their condensates (e.g. olivine, serpentine) but week change for other (e.g. pyroxene, enstatite). Near critical point vaporization of complex systems is characterized by volatilization of molecular clusters [6] which can become a dominant part of the vapor. Cited effect provides strong evidence for volatilization of Mg and Si from high-temperature melts as molecular clusters which have Mg/Si ratio about 1, or “enstatite” cluster. The effect is clearer for simple minerals while for complex samples it is obscured by multiple vapor components.

Thermodynamic evaluation was done using “Magma” code [9] which uses empirical model of ideal mixing of complex components in the silicate melt. Such an approach considers silicate melt as an ideal mixture of complex oxides and silicate pseudocomponents (clusters). The concentration of such pseudocomponents is proportional to their stability in the melt. Calculations shows that “enstatite” component is dominant in high-temperature melts (>2500 K).  $\text{SiO}_2$  has noticeable activity which provides framework features (see Fig. 3) in condensates. “Olivine” component rapidly decreases with growing temperature and gives low input of isolated features in condensates. MgO component is abundant in melts but shows volatility less than of “enstatite” cluster providing enrichment of melt residua in Mg.

Extrapolation of thermo-dynamic data to temperatures up to 5000 K shows that at temperatures over ~2500 K melts loses the domination of “olivine” clusters and “enstatite” clusters become dominant. This is the principal difference of vaporization in vacuum furnaces and impact-induced vaporization since temperatures 2500-3000 K is the physical threshold between these two methodics.

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**References:** [1] B.O.Mysen, J.Kushiro (1988) *American Mineralogist*, v. 73, p. 1-19. [2] H.Nagahara et al. (1988) *Nature*, v. 331, p. 516-517. [3] A.Hashimoto (1990) *Nature*, v. 347, p. 53-55. [4] J.D.Kubicki, E.M.Stolper (1993) *LPSC XXIV*, p. 829-830. [5] T.Sata et al. (1978) *Rev. Houtes. Refract., Fr.*, v. 15, p.237-248. [6] Gerasimov M.V., et al. (1998) *Earth, Moon, and Planets*, vol. 80, Nos. 1-3, pp.209-259. [7] O. I. Yakovlev, et al. (2006) *Geochemistry International*, vol. 44, No 9, pp. 847-854. [8] Gerasimov M.V., et al. (2002) *Deep-Sea Research Part II: Topical Studies in Oceanography*, vol. 49, No 6, pp. 995-1009. [9] B.Fegley,Jr, A.G.W.Cameron. *Earth and Planet. Sci. Lett.*, 82, 1987, p. 207.