THE CONDITIONS OF FeO-RICH OLIVINE FORMATION IN JOVIAN SUBNEBULAE

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The FeO-rich olivine formation with fayalite content more than 10 mol. % in the Solar nebula conditions was considered elsewhere [1]. It was shown that the formation was most likely to occur at the stage of the accretion of meteorite parent bodies ($\tau > 10^6$ years), according to the reaction:

$$2MgSiO_{3(s)} + 2Fe_s + 2H_2O_g = Fe_2SiO_{4(s)} + Mg_2SiO_{4(s)} + 2H_{2(g)} \quad (1)$$

at $T > 1000 - 1200$ K, when there were no constraints for the reaction (fig.1).

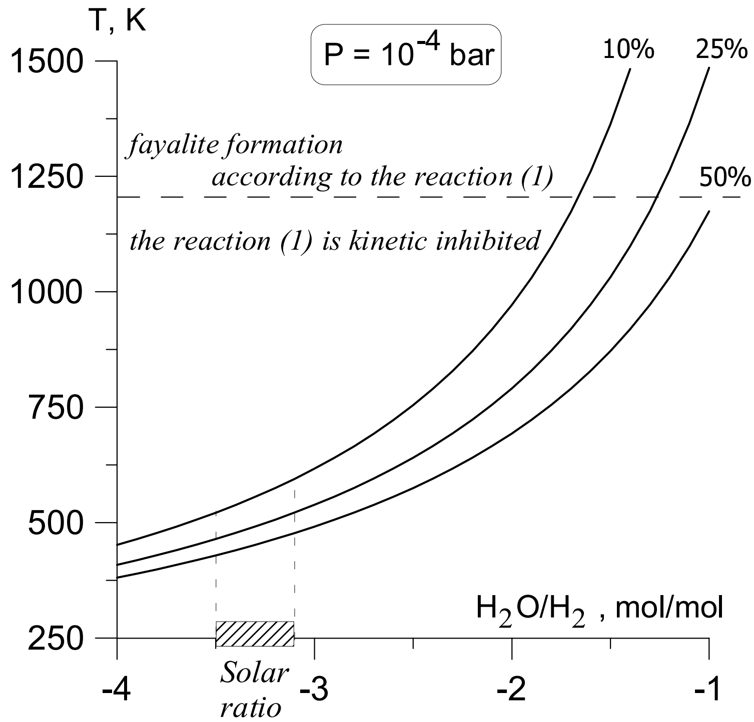

Fig.1. Fayalite content in olivine (mol. %) under different temperature conditions depending on the $(H_2O/H_2)_g$ ratio. It was calculated based on the thermodynamic equilibrium constant of the reaction (*1*), which could be approximated as followed:

$$lgK_{(1)} \approx lg\left[x_{Fa}^{Ol}\left(1 - x_{Fa}^{Ol}\right)\cdot p_{H_2}^2 / p_{H_2O}^2\right]$$

The $(H_2O/H_2)_g$ ratio in the Solar composition gas ($T \leq 700$°K) is marked as *"Solar"*. The $(H_2O/H_2)_g$ ratio depends on the degree of advancement of the reaction:

$$CO + 3H_2 = CH_4 + H_2O,$$

and on the extent of CO conversion into organic compounds by FTT synthesis:

$$nCO + (n+m)H_2 = C_nH_{2m} + nH_2O$$

Elevated temperatures and high $(H_2O/H_2)_g$ ratio could be attained during intercollisions of large and compare-sized bodies (planetesimals) (R ~ 100 km) with relative velocities ≥ 5 km/c [2] and $(H_2O)_{ice}/SiO_2$ = = 1 – 2.5 mol/mol. However, due to the moderate chaotic movement rates of the bodies in the Solar nebula combined with the body size distribution, the proportion of such impacts seems to be small, as well as the mass of the substance subjected to the impact processing. At the same time analysis of physical and physico-chemical conditions in the Jovian subnebulae has shown, that these are more favourable to formation in it of the olivine with high FeO content through the mechanism considered above.

Really, the reaction (*1*) proceeds when two conditions are fulfilled: 1 – the high speed impacts of the bodies with Fe-silicate composition which results in local T increasing up to 1000 – 1200°K, and 2 – the ice in these bodies exists in sufficient amounts to ensure in a forming cloud the $(H_2O/H_2)_g$ ratio several times over the Solar one. The performed analysis shows that in the Jovian subnebulae the both conditions are fulfilled.

1. The Jovian subnebulae was formed at the late stage of the planet formation, when it contained more than half of its mass ($\tau \geq 10^7$ years). In this period, in the Jupiter zone of the Solar nebula (the radial distance $r \sim 4$ AU) the main mass (~ 80 %) of substances was contained in the large bodies (with radius R ~ 100 – 1000 km). Radial drift of such bodies to the Sun did not depend on radial drift of gas. When the bodies came under the gravitational influence of the forming Jupiter, they came across the Jovian disk (subnebulae). Their relative velocities were above ~ 10 km/sec in the Ganymede - Callisto zone of the Jovian subnebulae, and above ~ 20 km/sec in the Io – Europe zone. Jupiter captured a part of the bodies, and the others impacted with large bodies formed in the Jovian subnebulae. This resulted in their fragmentation, partial evaporation, and subsequent partial recondensation of material. The temperatures in the expanding explosion clouds at planetesimals collisions up to ~ 1500°K and pressures – up to ~ 10 bar. This provided thermodynamic conditions for heterogeneous reaction (*1*). The resulting substances remained in the disk, partially captured by the Jupiter, as well as by the forming Jovian regular satellites. Comparing lifetime of the bodies with R ~ 100 – 1000 km ($\tau \geq 10^5$ years) with accumulation time of the Galilean satellites ($\tau \geq 10^6$ years) we could find that these bodies were repeatedly subjected to the destruction (with the exemption of the embryo of the satellites formed very quickly: $\tau \sim 10^5$ years).

2. The volatile abundances in the large planetesimals captured at the late stage of the Jupiter formation could be estimated based on the current data on the Jupiter atmosphere. It is enriched with Kr and Xe as well as C, N, S by about a factor 3 [4]. Estimated O/H ratio on the 1 bar pressure level was equivalent to the Solar value [5] and 3 – 10 times of this in as a whole. The formation of such ice planetesimals with Solar proportion of Kr, Xe, N, C and S in the Solar nebula could be proceeded at the temperatures below 75°K. At these temperatures, the water ice captured CO, CH_4, H_2S, N_2, NH_3, Kr, Xe from ambient gas phase of the nebula. Thermodynamic conditions of formation such ice planetesimals in the Solar nebula, according to the [6,7] model are shown in Fig.2.

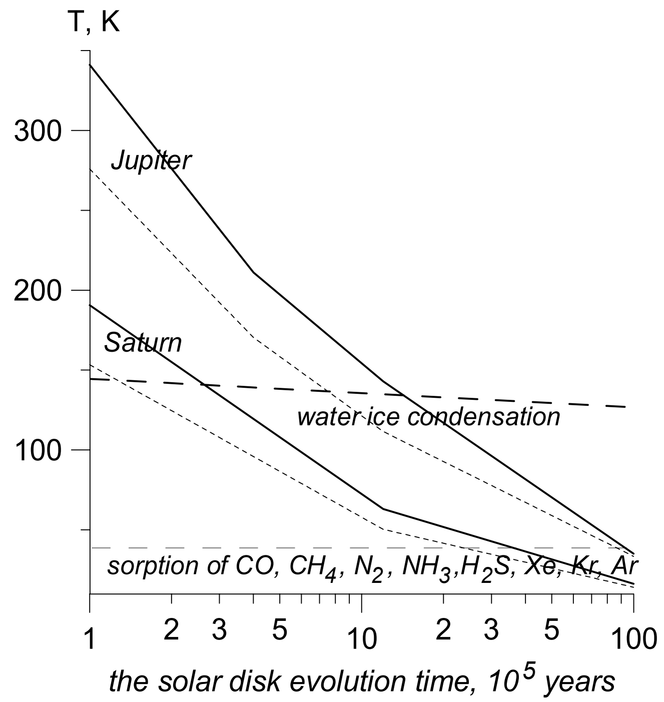

Fig. 2. The time dependence of the temperature for the Jupiter (r_J) and Saturn (r_S) radial distances, model [6,7]. The temperature of the water ice condensation is achieved at the r_J about 10^6 years. During the next 10 millions years the ice captured the nebula gases. Therefore, the ice/rock ratio in these bodies could be several times the Solar value. On the late stage of Jupiter accretion ($\tau > 10^6$ years) these planetesimals could be captured by the planet.

So, there were favorable physical and chemical conditions in the Jupiter subnebulae for the formation of abundant of Mg-silicates with high FeO-content. These FeO-rich silicates could form the main mass of substances of the Galilean (regular) satellites. This conclusion agrees with the current models of the interior structure of Io and Europe [8].

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