ESTIMATION OF THE COMPOSITION AND MASS OF THE ICE COMPONENT IN PRIMARY STONE-ICE PLANETESIMALS OF THE NEAR-SOLAR DISK. E. A. Generalova and V. A. Dorofeeva, Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Kosygin str., 19, 119991, Moscow, Russia, lisa.generalova@yandex.ru

Introduction: Estimating the composition of primary planetesimals is crucial for modeling formation and internal structure of bodies in the Solar System. In this paper, the composition of rock-ice planetesimals, particularly their ice component, and its mass fraction, depending on the formation region, is considered. We use methods of equilibrium thermodynamics, the distribution of temperature and pressure in the protoplanetary disk during its evolution, the elemental and chemical composition of the nebula.

Results and discussion: In order to estimate the radial distribution of temperature and pressure in the solar nebula, we used models of the internal structure of the gas-dust accretion protoplanetary disk ([1], [2]). Results show that at the final stage of its evolution, the H_2O_{ice} snow line moved up to the outer boundary of the Main Asteroid Belt. This created conditions for the accumulation of water ice in the bodies in this region.

For the inner zone of the nebula, up to the asteroid belt, the M_{H2O}/M_{solid}=1.17 estimate was given in [3]. In it, the solid phase composition was similar to the composition of EH-type enstatite chondrites. However, the formation of it requires more reduced conditions: C/O~0.85-1 ([4]). The ratio, obtained in [3] is overestimated since its calculation did not take into account oxygen-containing gases other than H_2O, especially CO and CO_2.

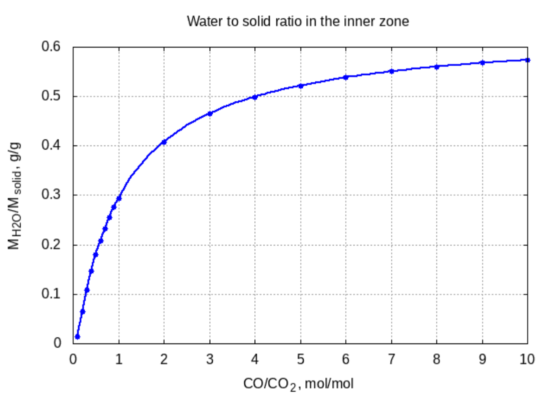

Fig. 1. The maximum possible values of the ratio of the ice mass of water and mineral components in planetesimals formed in the inner zone of the nebula. Solar system abundances by [5].

We estimated the possible ratio of the mass of water to the mass of the refractory component, which in the inner part of the near-solar nebula included exclusively mineral phases; the results are shown in Fig. 1. Thus, it follows that the proportion of water in the proto-bodies formed in the inner zone did not exceed 0.375, which is close to the value obtained for Ceres in the recent Dawn experiment ([6]).

Let us consider the composition of primary planetesimals in the formation zone of Jupiter and Saturn. As the temperatures in this zone did not exceed 500 K, it follows that the refractory organic substance, also known as CHON, was not thermally destroyed. 0According to current estimates based on the composition of comet dust ([7]), it contained from 30 to 50% of the total carbon content in the system (C_{tot}). Following [8], we accepted its formula as $C_{100}H_{70}O_{20}N_4$. Thus, the solid phase composition indicated in Fig. 2 is calculated as the sum of the masses of the mineral component (similar to the composition in the inner zone) and CHON with a variable proportion of fraction of total carbon. The ice component in the Jupiter region could contain only H_2O since the condensation temperatures of all other gases are lower than those that could be attained in this region. The results are shown in Fig. 2.

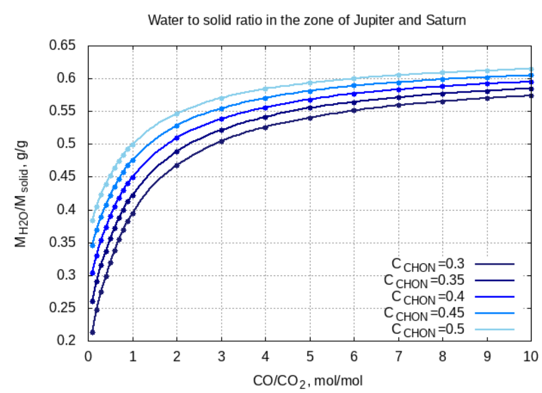

Fig. 2. M_{H2O}/M_{solid} in planetesimals formed in the zone of Jupiter and Saturn, depending on the value of the molar ratio of CO/CO_2 in the nebula and the content of CHON in it.

However, the ice had a more complex composition in the Saturn region. It can be assumed that in the addition to water, it could also contain CO_2, CH_3OH, NH_3, and HCN in its composition.

According to the data on the composition of interstellar molecular clouds [9], we assume the molar fraction of ammonia to be ~10% N, and CH_3OH and HCN did not exceed 1%. The composition of the solid component is assumed to be the same as for the Jupiter region. The ratios of the masses of ice and the refractory component M_{ice}/M_{solid} could vary widely: from 1.2 to 0.7, as shown in Fig.3.

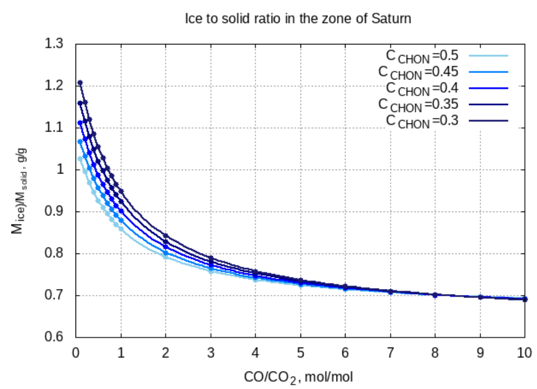

Fig. 3. M_{ice}/M_{solid} in planetesimals formed in the Saturn region, depending on the molar ratio of CO/CO_2 in the nebula and the content of CHON in it.

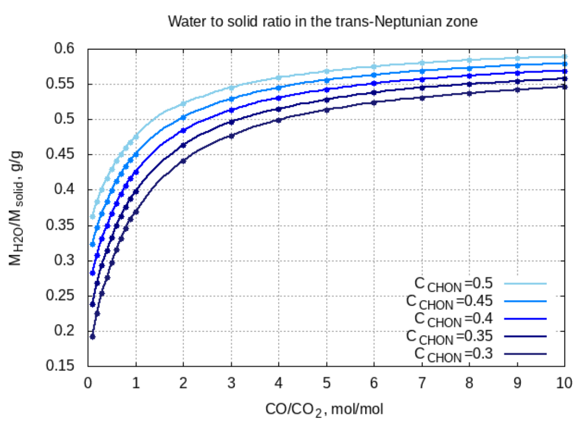

Fig. 4. M_{H2O}/M_{solid} in planetesimals formed in the trans-Neptunian region, depending on the value of the molar ratio of CO/CO_2 in the nebula and the content of CHON in it.

In trans-Neptunian region, in addition to Mg-silicates, the mineral component of refractory components should include Fe-Mg-silicates of extrasolar origin [10]. In this calculation, we assumed that the parts of Fe^0 and FeO are equal. M_{H2Oice}/M_{solid} does not exceed 0.6 g/g, and the mass fraction of H_2O_{ice} does not exceed ~ 0.35. This result does not contradict the opinion that the proportion of water ice in cometary nuclei is ~ 0.25. Nevertheless, to accept the point of view that it can be 0.17, expressed in several papers ([11], [12]), it should be assumed that there is no CO_2 in the solar nebula at all, and the proportion of carbon that is part of CHON is no more than 0.2. These assumptions contradict known data on the composition of cometary nuclei (see [7]).

Conclusions: Estimates of the composition and relative content of the ice component in different regions of the early Solar system were obtained.

1. For the inner region, only water ice was part of the ice, and its fraction in the rock-ice proto-bodies did not exceed 0.375, which is close to the value obtained for Ceres in the recent Dawn experiment.

2. In the region of the formation of the Jupiter and Saturn systems, the refractory component of the rock-ice planetesimals included, in addition to the mineral component, also refractory organic compounds of the provisional composition $C_{100}H_{70}O_{20}N_4$ (CHON). It was found that the maximum possible value of the H_2O_{ice}/solid ratio in this zone is ~ 0.6 g/g. The maximum proportion of water in the composition of the regular satellites of Jupiter and Saturn most likely could not exceed ~ 40 wt%.

3. In the Saturn system formation zone, the ice included CO_2, CH_3OH, NH_3, and HCN, as well as H_2O. With variations in the values of the molar CO/CO_2 ratios in the system and the content of CHON in it, the values of the mass ratios of ice and the refractory component Mice/Msolid could vary widely: from 1.2 to 0.7. They approach 1 and even exceed it with a decrease in the content of CHON in the refractory component and low values of CO/CO_2.

4. For the trans-Neptunian region, the value of the ratio of the masses of water ice and the refractory component in the rock-ice planetesimals with the same parameters is less than in the Saturn and Jupiter zone: it does not exceed 0.6 g/g, and the mass fraction of H_2O_{ice} is not higher than ~ 0.35. The value of M_{ice}/M_{solid} very weakly depends on the change in the ratio of CO and CO_2 and is mainly determined by the proportion of carbon included in the refractory component.

References: [1] Makalkin A. B. and Dorofeeva V. A. (1995) *Astr.Vestn., 29, 2*, 99-122. [2] Makalkin A. B. and Dorofeeva V. A. (1996) *Astr.Vestn., 30, 6*, 496-513. [3] Lodders K. (2003) *ApJ, 591*, 1220-1247. [4] Dorofeeva V. A. et al. (1982) *LPS XIII*, 181-182. [5] Lodders K. (2010) *ASSP*, 379-417. [6] Zolotov M. Yu. (2020) *Icarus, 335*, A113404. [7] Dorofeeva V. A. (2020) *Sol.Sys.Res., 54, 2,* 96 –120 [8] Alexander C.M.O'D. et al. (2007) *GeoCoA, 71*, 4380-4403. [9] Müller et al. (2021) *A&A, 652*, A126. [10] Dorofeeva V.A. (2022) *Sol. Sys. Res. (in press)*. [11] Rotundi et al. (2015) *Science, 347, 6220*, aaa3905. [11] Moreno et al. (2016) *ApJ, 826*, 137.