WATER AND VOLATILES INVENTORY FROM BEYOND JUPITER'S ORBIT TO THE TERRESTRIAL PLANETS AND THE MOON

M. Ya. Marov and S. I. Ipatov, V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences, Kosygina st., 19, Moscow 119991, Russia (marovmail@yandex.ru, siipatov@hotmail.com)

Introduction: The ocean terrestrial water could be a result of mixing of water from several sources, including the deep mantle water with a low D/H ratio. The deep mantle water could be acquired due to adsorption of water on fractal grains during Earth's accretion [1]. The outer asteroid belt is often considered to be the main source of the delivery of water to the terrestrial planets [2]. The key argument against an asteroidal source as the main source of Earth's water is that the O's isotopic composition of Earth's primitive upper mantle matches that of anhydrous ordinary chondrites, not hydrous carbonaceous chondrites [3].

Migration of planetesimals to the terrestrial planets: In [4] we presented the results of our computer simulations of migration of 10^4 planetesimals from the feeding zone of Jupiter and Saturn to forming terrestrial planets under the gravitational influence of planets. In series JN, all planets were considered in present orbits with present masses. In series JS, Uranus and Neptune were excluded. The initial semi-major axes of the planetesimals were between 4.5 and 12 AU. Their initial eccentricities and inclinations were 0.3 and 0.15 rad, respectively. Masses of planets moving in the orbits of the terrestrial planets were equal to present masses of the planets in series JS and JN, and in series JS_{01} and JN_{01} they were smaller by a factor of 10 than the present masses. The probability p_E of collisions of the planetesimals with the Earth of mass m_E during the dynamical lifetimes of planetesimals was obtained to be about 2×10^{-6}. For the mass of the Earth embryo equal to $0.1m_E$ the probability was 4×10^{-7}. In the runs for which the giant planets of present masses initially were located more close to each other than the present giant planets, the values of p_E were usually not smaller than the values of p_E for series JS, JN, JS_{01} and JN_{01}. To our estimates, during the growth of the Earth's embryo mass up to $0.5m_E$, the amount of water delivered to the embryo from the feeding zone of Jupiter and Saturn could be about 30% of the total mass of water delivered to the Earth from this feeding zone. In our previous calculations of the migration of the objects which initially moved in orbits close to Jupiter-family comets, p_E exceeded 4×10^{-6} [5-7]. For the total mass of planetesimals in the feeding zone of Jupiter and Saturn equal to $100m_E$, at $p_E=2\times10^{-6}$, and for planetesimals consisted half in water, the planetesimals from this feeding zone could deliver about a half of Earth's ocean water. A similar amount of the water could come from more distant regions. In series JS, the ratio of the mass of water delivered to a planet to the mass of the planet for the Earth was smaller by a factor of 2, 1.25, and 1.3 than that for Mars, Venus and Mercury, respectively. For series JN, the above factor equaled to 3.4, 0.7 и 0.8, respecrively.

Probabilities of collisions of planetesimals with the Moon: The probabilities of collisions of planetesimals with the Moon in our series of calculations varied from 7×10^{-8} to 2.7×10^{-7}, and in a half of the series they were approximately 1.2×10^{-7}. The ratio p_E/p_M of the probability of collisions of planetesimals with the Earth to the probability of their collisions with the Moon was in the range from 16.5 to 16.7. This range is for the number of planetesimals in an each series of runs not smaller than 2000. For 250 planetesimals in each run the ratio p_E/p_M varied from 16 to 17. For comparison, the square of the ratio of the radii of the Earth and the Moon is 13.48. The probability of a collision with the Moon (or with any planet) in diferent runs with only 250 planetesimals could differ by a factor of more than 10 for the same series of runs. The mass of planetesimals and water delivered to the Moon from beyond of the orbit of Jupiter could be less by a factor of about 20 than that delivered to the Earth. The ratio of the probability of collisions of planetesimals with the Moon of mass m_M to the probability of the collisions of planetesimals with the Moon embryo of mass $0.1m_M$ was about 4.7. The values of the p_E/p_M ratio were also calculated for migration of objects whose initial orbits were close to orbits of Jupiter-family comets [5-7]. These values varied from 15.2 to 17.6 for runs with 250 objects. For asteroids from the 3:1 resonance with Jupiter, p_E/p_M reached 18.6, and for comets with eccentricity e=0.975 it was equal to 15.2. The ratio of the probability of collision of bodies with the Moon at its current density to the probability at Moon mass with the Earth's density was close to 1.39 in all calculations.

The work was supported by the Program of Fundamental Studies of the Presidium of RAS № 17 as a part of Russian state program for GEOKHI N 00137-2018-0030 (migration of planetesimals to the terrestrial planets) and by the grant of Russian Science Foundation N 17-17-01279 (planetesimals' migration to the Moon).

References: [1] Hallis L. J. (2015) *Science* 350:795-797. [2] Petit J.-M. et al. (2001) *Icarus* 153:338-347. [3] Drake M. and Campins H. (2006) *IAU Symp. 229 "Asteroids, Comets, & Meteors"*: 381-394. [4] Marov M. Ya. and Ipatov S. I. (2018) *Solar System Research* 52: N 5, in press. [5] Ipatov S. I. and Mather J. C. (2004) *Advances in Space Research* 33:1524-1533 (http://arXiv.org/format/astro-ph/0212177). [6] Ipatov S. I. and Mather J. C. (2006) *Advances in Space Research* 37:126-137 (http://arXiv.org/format/astro-ph/0411004). [7] Ipatov S. I. and Mather J. C. (2007) *Proc. of the IAU Symp. No. 236 "Near-Earth Objects, Our Celestial Neighbors: Opportunity and Risk"* Cambridge University Press: 55-64 (http://arXiv.org/format/astro-ph/0609721).