MIGRATION OF DUST PARTICLES AND VOLATILES DELIVERY TO THE INNER PLANETS. M. Ya. Marov, *M.V. Keldysh Institute of Applied Mathematics, Russian Academy of Sciences, Miusskaya sq. 4, Moscow 125047, Russia (marov@spp.keldysh.ru)*, S. I. Ipatov, *University of Maryland, USA (siipatov@hotmail.com)*.

Introduction. Delivery of volatiles by small bodies to the terrestrial planets in terms of formation and evolution of their atmospheres/hydrospheres was earlier discussed by us [1-4]. We shall now address the role of dust particles in such a delivery. Particulate matter is produced by comets, trans-Neptunian objects, and asteroids. These interplanetary dust particles (IDPs) migrate in the Solar System and can collide with terrestrial planets, some trans-Neptunian objects getting first Jupiter-crossing orbits. Our results of computer simulations showed [5-6] that a small fraction of Jupiter-crossing objects (JCOs) can transit to the orbits typical for near-Earth objects and even to typical asteroid orbits, and some of them reside such orbits for tens or even hundreds of millions years. One may thus assume that many former comets composed mainly of late condensates and carbonaceous chondrites and closely related to trans-Neptunian objects, disintegrated inside Jupiter's orbit during this long period of time giving rise to enormous amount of dust particles of primordial origin. In pursuit of these basic ideas, migration of dust particles from different regions of the solar system was numerically integrated [7-8]. In evaluating asteroid and trans-Neptunian particles migration, we started from numbered main-belt asteroids and known trans-Neptunian objects, whereas comets 2P Encke and 10P Tempel 2 were selected as representative source of comet debris production. The refined model will be discussed with the goal to evaluate a potential contribution of dust particles in the delivery of volatiles to the terrestrial planets.

Results of the modeling. Collision probability P with the Earth of dust particles with genesis to asteroids was found [7-8] to have a maximum ($\sim$0.001-0.02) at 0.002$\leq\beta\leq$0.01 (where β is the ratio of the radiation pressure to the gravitational force and P is a value for one particle), i.e., for the particle diameters $d\sim$100 μm. This is in accordance with cratering records in the lunar soil and also with particles record on the panels of the Long Duration Exposure Facility, which showed that the mass distribution of dust particles encountering Earth peaks at d=200 μm. For Venus P values didn't differ much from those for Earth, whereas for Mars they were by an order of magnitude smaller at $\beta\geq$0.01 compared to Earth, and nearly similar to those for Earth at $\beta\sim$0.0004-0.001.

Collision probability P with terrestrial planets of the Comet 10P dust debris, was found to be only a few times different compared to that for particles generated by asteroids. In turn, for Comet 2P dust debris, the P values were found usually smaller than for asteroid and comet 10P particles: for Earth at 0.002$\leq\beta\leq$0.01, P were by an order of magnitude smaller for 2P particles than for asteroid particles. For 2P particles at some β, P is by the factor of 2 or 4 greater for Venus than for Earth.

Collision probabilities P of trans-Neptunian particles with Earth and Venus at 0.01$\geq\beta\geq$0.2 were $\sim (0.3{-}4)\times10^{-4}$ and were usually less than those for asteroid particles by the factor of less than 4.

Another source of interest is interstellar particles transiting the planetary system with hyperbolic velocities and becoming increasingly important beyond R =3 AU from the Sun where they appear to dominate micron- and submicron-sized interplanetary dust. Direct collisions of these particles with terrestrial planets is expected to be negligible. However, interstellar particles can be effective in destruction of trans-Neptunian dust particles through collisions, especially with grains between 9 μm and 50 μm, as it is argued in [9]. Larger particles may survive because interstellar grains are too small to destroy them in a single impact. Since the total mass of the trans-Neptunian belt exceeds that of the asteroid belt by more than two orders of magnitude, and the derived in our model mean residence times ratio in orbits with perihelion distance q<1 AU for asteroid and trans-Neptunian particles is less than 20 at $\beta\geq$0.05, then for $d\sim$1-10 μm the fraction of trans-Neptunian dust of the overall dust population can be significant even at R<3 AU. These particles should not be icy, however, because they easily evaporate when approaching the near-Earth and other inner planets space [9].

Volatiles Delivery. It is reasonably assumed that collisional interaction of planetesimals resulted in enormous dust production in due course of the planets formation. Numerous planetesimals from the zone beyond Jupiter's orbit resided Jupiter-crossing orbits which could be similar to the orbits of Jupiter-family comets, with their follow up disintegration and/or migration inward the solar system.

It was earlier shown [2-6] that even a relatively small portion ($\sim$0.001) of JCOs which transit to orbits with aphelia inside Jupiter's orbit (Q<4.7 AU) and reside such orbits during more than 1 Myr may contribute significantly in collisions with the terrestrial planets and thus deliver significant amount of volatiles. Assuming that the mean collision probability of JCOs with Earth is $P_E = 4\times10^{-6}$ and the total mass of planetesimals that crossed Jupiter's orbit is $\sim 100 m_E$ (where m_E is the mass of Earth) we found that the total mass of comet- asteroid-like bodies which impacted Earth was $4 \times 10^{-4} m_E$. Assuming further that ices represented a half of this mass, we estimated the total mass of ice that was delivered to Earth from the feeding zone of giant planets to be roughly equal to the mass of the Earth's oceans. Venus received nearly equal amount of ice, while Mars accreted more comets per a unit of the planet's mass than Earth and Venus.

Basically, contribution of dusty matter in the volatiles inventory to the inner planets is difficult to assess accurately. Our model testifies that for one object the collision probability of dust debris of Jupiter-family comet origin is roughly 2-3 orders of magnitude higher as compared to their parent bodies. Evidently, despite such a high probability for particles with size distribution peaking at 100 microns, their contribution to the total volatiles delivery is relatively small. This is supported independently by the well known estimate of fine dust of extraterrestrial origin falling down daily onto the Earth's surface averaging at 4×10^7 g, which corresponds to 5×10^{19} g storage for the last 3.5 Gyr and is probably one or two orders of magnitude higher during and soon after period of heavy bombardment. If one assumes that volatiles composed about one tenth of the dusty matter, its total mass delivered to the Earth still remains at the level of less than 10^{21} g, i.e. three to four orders of magnitude less compared to the volatiles inventory by comets and asteroids.

Our assumption of ten percent volatiles fraction in the particles composition seems plausible. Indeed, the most volatile-rich debris from trans-Neptunian region can hardly survive the near-Earth and other inner planets environment. On the other hand, significant part of dust particles within Jupiter's orbit is composed of carbonaceous chondrites enriched with volatiles (of CI chondrites type). These particles seems originated under low temperatures from a very primitive solar material, as it is the case for comets, in support of the idea of genetic relation between comets and IDPs [10]. They can be thus abundant with H, O, C, and N bearing compounds.

Although dust debris did not contribute much to the postulated exogenic mechanism of geterogeneous accretion [11], they are thought to play significant role in the inner planets evolution and, in particular, in the delivery of organic matter they could be more efficient than larger bodies. As a matter of fact, small grains do not experience great heating (up to evaporation) when penetrating planetary atmosphere because of a high surface area-to-mass ratio that enables them to effectively radiate excessive heat. Therefore, they may sediment gently through an atmosphere onto the surface and bring essentially non-modified original interplanetary or even inerstellar matter. This allows us to address dust debris as potential carriers of biogenic forms from outermost regions, in addition to matter exchange transport between the inner planets. From this viewpoint, it seems unlikely to find Martian life forms (if any) different from our own.

Conclusions. The model of particulate matter migration in the solar system was developed in order to evaluate it efficiency in the volatiles delivery to the inner planets. It is emphasized that cometary and trans-Neptunian dust particles can play an important role in collisions with the terrestrial planets.

Contribution of dust particles in the volatiles inventory to the inner planets is difficult to assess accurately. Nonetheless, their contribution is estimated about three to four order of magnitude less compared to comet-asteroid impacts. Dust particles could be, however, most efficient in the delivery of organic matter surviving atmospheric entry and, in particular, to serve as potential carrier of primitive biogenic forms.

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