ISSN 0236-2457
ASTRONOMICHESKII TSIRKULYAR
Published by the Eurasian Astronomical Society
and Sternberg Astronomical Institute
No. 1615, 2014 November 10

STONE-ICE BODIES AS POSSIBLE INCUBATORS OF A PRIMARY LIFE[1]

V.V. Busarev
Moscow State University, Sternberg Astronomical Institute
13 Universitetskij prospekt, Moscow, 119234 Russia
E-mail: busarev@sai.msu.ru

Received September 4, 2014

Abstract. It is shown that in the early Solar System, during the first few millions of years, objects on which existed conditions for spontaneous origin of life were probably stone-ice bodies. Decay of short-lived isotopes (primarily ^{26}Al) in the silicate fraction of matter became the main energy source for the formation of an abundant aqueous medium or even a global internal water ocean, where a primary life could be formed. Such early processes (melting water ice, forming aqueous medium and then water differentiation and accumulation of a silicate-organic core) were to occur on all large stone-ice bodies (>200 km) of the Solar System beyond the "snow-line", in particular, in the formation zone of Jupiter. The supposed formation of primitive life forms, which happened probably in the nucleus of one or several rock-ice objects ejected by proto-Jupiter to internal Solar System, could continue on larger Earth-like planetary bodies with suitable conditions.

Widespread in the interstellar medium three-atomic molecules of HCN and H_2O and derivative from them formamid (NH_2COH) are the basis for the origin of life. As shown in laboratory experiments (JINR, Dubna, Russia) [1], irradiation of formamid by protons in the presence of mineral or meteoritic catalysts leads to synchronous synthesis of a wide range of prebiotic compounds (amino acids, heterocycles, alcohols, amides, sugars, etc.) having potential to develop as genetics (based on RNA and DNA) and metabolism underlying terrestrial life forms [2, 3]. It is important to emphasize that such sort of synthesis is abiotic and runs in the same chemical medium. As suspected, proton irradiation of formamid creates active radicals stimulating effectively a further synthesis up to extraterrestrial prebiotic forms.

However, the intended path of the chemical evolution in the open interstellar medium could not reach its logical end. The subsequent stages of the assumed biological synthesis needed a protection from the harsh cosmic factors and presence of liquid water, catalysts, etc. (e.g., [4]). Such conditions could be realized only on planetary bodies and/or in their interiors. From observations [5, 6] and calculations [7], the author suggested that the objects could be in the early Solar system. For the first few million years, conditions for spontaneous origin of the basic prebiotic compounds probably existed within stone-ice bodies. Decay of short-lived isotopes (primarily ^{26}Al with $T_{1/2} = 0.72$ My, e. g., [8]) in the silicate fraction of matter

[1] Talk presented at the Interdisciplinatory Colloquium on Cosmic Factors of Evolution of the Biosphere and Geosphere, Moscow, May 21–23, 2014.

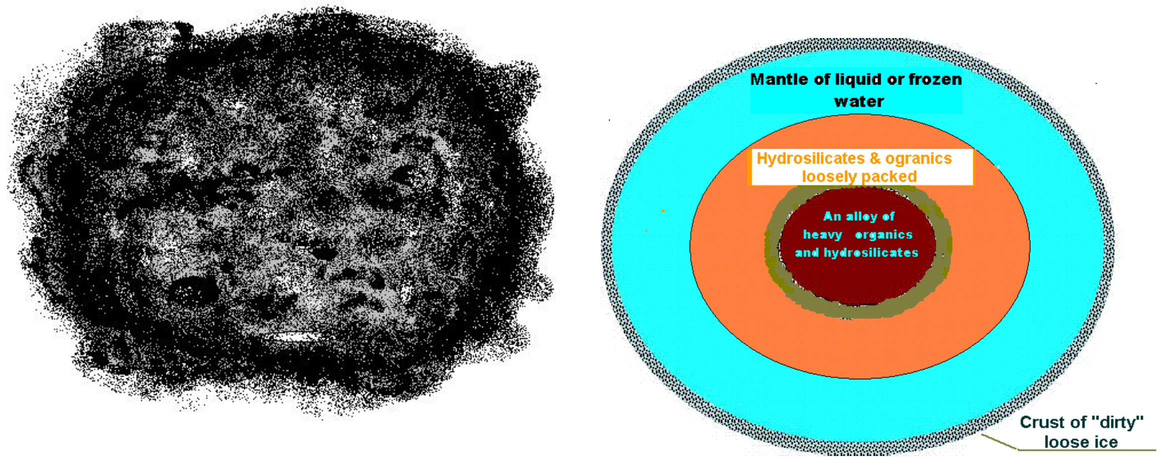

Figure 1: (a, b) Models of undifferentiated (a) and water-differentiated layered stone ice body (b) outside of the "snow-line" in the early Solar system.

became the main energy source for the formation of an abundant aqueous media or even a global internal water ocean at a temperature of ~ 4°C [7]. Such early processes (melting water ice, forming aqueous medium and then internal ocean, water differentiation and accumulation of a silicate-organic core) were to occur on all large stone-ice bodies (>200 km) of the Solar system beyond the "snow-line". The early thermal evolutionary process one can be imagined as a gradual heating of rock-ice bodies at decay of ^{26}Al, which was to begin in primary formless but gravitationally bound planetesimals. Figure 1(a) shows one of such initially formless body, heating of which made it plastic, and then its form was styled by the gravitational force to a spherical one and its interiors divided into spherical shells and a nucleus with size up to $\sim 0.7R$ (Fig. 1, b) [7]. The bodies in the formation zone of Jupiter must ^{26}Al leading to elevated temperatures in their interiors. We can assume that into their silicate-organic cores were more favorable conditions for the origin and developing of not only hydrated silicates and simplest organic compounds (kerogen or bitumen type), but the main pre-biotic compounds (amino acids, etc.) and possibly biological anaerobic structures like prokaryotes.

Approximately in the same period of time, when the mass of proto-Jupiter reached $\sim$5–10 Earth's masses, its accretion of smaller rock-ice bodies changed by their predominant ejection far outside of the zone, both to external and inner parts of the Solar system [9, 10]. The range of velocities of the bodies which penetrated into the asteroid zone was estimated approximately as 2–3 km/s up to 30 km/s [10]. Their direct collisions with the highest velocities with the parent asteroid bodies would lead to a mostly complete sweeping out them from the asteroid belt. This extreme case of collisional interaction of the bodies was considered as the main mechanism of matter removal from the asteroid zone (e. g., [9, 10]). However, calculations and experiments show that in any case of collisions some parts of the "targets" and "impactors" remain in vicinity of the collisional epicenter. It implies that along with removal of matter from the asteroid zone at such collisions, its delivery took place. "Delivered material" means large and smaller fragments (including blocks and pieces of water ice) of bodies from Jupiter's zone remained in the asteroid belt. Apparently, a share of the delivered matter was the greatest in the case of collisions at the smallest velocities. It is important to note that the bodies penetrated into the asteroid belt with minimal velocities (favorable for survival of all low-temperature materials such as water ice, hydrated silicates and organics) had the highest probability to collide with asteroid parent bodies. They moved in orbits with the lowest eccentricities and approached to asteroids more often and over a more extended time than those having the highest velocities and moved on elongated orbits. After the catastrophic collisions, the survived largest fragments of the bodies from the formation zone of Jupiter could remain there and constitute or replenish the number of primitive asteroids with low-temperature mineralogy (of C-, B-, F-, and other types). Their smaller fragments (ice and carbonaceous matter of the CI-type) reprocessed at collisions could reaccrete on the nearest asteroids and formed different groups of carbonaceous chondritic matter of (CM, CO, CV, etc.) depending on the relative abundance of high-temperature millimeter-size inclusions or "chondrules". Such a scenario corresponds to our hypothesis on the formation of primitive type asteroids and carbonaceous chondrites [11]. It is in accordance with a mechanism of origin of chondrules as droplets of melted and quickly cooled materials at collisions of asteroid-size bodies [12–14]. Main features of carbonaceous chondrites, as transporters of pre-biotic compounds, established at laboratory investigations of properties of the known samples of meteorites. Note some other important features of them, which confirm our hypothesis on their origin [11]. Carbonaceous chondrites of chemical groups CI and CM are the most primitive geological compounds in the Solar system. Their temperature never exceeded 150°C (e. g., [15]) and they have solar composition (excluding H and He) [16]. There are no chondrules in CI-chondrites at all and they consist only of water-modified amorphous hydrosilicates, which were formed in abundant aquatic environment [15]. However, CI carbonaceous chondrites include only a few amino acids, and CM carbonaceous chondrites contain up to 80 types of amino acids [17]. The fact points apparently to different evolutions of the meteorites. A supposition is made that a partial homochirality (a possible proximity to bio-compounds?) of amino acids in CI and CM carbonaceous chondrites originated in water conditions [18]. At the same time, there is an experimental evidence that homochirality rises in unidirectional magnetic field of plasma torch or shock plume at collisions of asteroid-size primitive bodies (including hydrosilicates) at velocities of the order of several km/s [19].

On the other hand, accumulation and burial of a considerable amount of water ice on asteroid bodies at the considered collisions could lead to next stages of aqueous alteration and rock formation in their interiors. Reaction of serpentinization or conversion of anhydrous silicates of pyroxene and olivine types to hydrosilicate of serpentine type is exothermic, i.e., when it occurs, the amount of heat allocated becomes sufficient for complete melting of the present water ice. In addition, there is a significant release of gases (CH_4 and H_2) in this process. Numerical modeling has shown that it could result in accumulation of sufficient amounts of the gases for the explosion and destruction of the evolving planetary bodies [20, 21]. Figure 2 schematically shows the process of successive water changes of an initially anhydrous substance of the asteroid in the case of burial of water ice in the depths of the body and its subsequent melting. Repeated impacts and decay of remained short-lived radionuclides might have been the main heat sources that could re-start and continue the processes of carbonaceous chondrites formation into the asteroid bodies. The possibility is supported evidently by last discoveries of cometary activity of some asteroids in the Main belt [22, 23].

In accordance with the law of kinetic energy conservation, the prevailing part of the fragments of the bodies from Jupiter formation zone must moved to the center of the Solar system and reached probably the terrestrial planets. The effects of the Poynting–Robertson and Yarkovsky were apparently the main factors of the transfer of such crushed materials in the central direction. The intensity of the primitive matter flow to the terrestrial protoplanets, perhaps, had a maximum over the period of the first several dozens or even hundred My. But due to repeated mutual collisions of asteroids in the Main belt, the migration of carbonaceous chondrite matter inside the Solar system has lasted up to nowadays. Thus, the supposed formation of pre-biotic compounds or even primitive life forms, which happened probably in nucleus of one or several rock-ice objects could continue on larger Earth-like planetary bodies with suitable conditions.

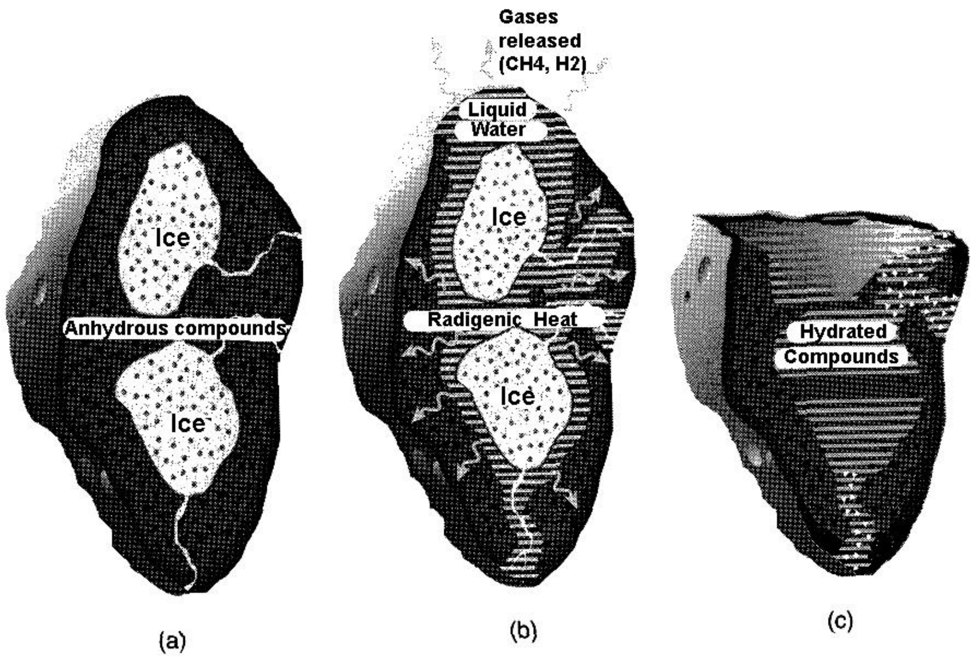

Figure 2: Illustration of internal thermal evolution of an asteroid with buried water-ice at the period of ^{26}Al decay. Disruption of the body was possible at the stage “c” because of an intense release of gases (CH_4 and/or H_2).

References

1. Saladino R., Botta G., Delfino M. et al. News of JINR [ISSN 0134-4811], `http://www.jinr.ru/News/News_4_2013.pdf` (2013).

2. Pino S., Costanzo G., Giorgi A. et al. Entropy **15**, 5362–5383 (2013).

3. Saladino R., Botta G., Pino S. et al. Chem. Soc. Rev. DOI: 10.1039/c2cs35066a (2012).

4. Mukhin L.M. In: The problems of life origin (Eds. L.I. Grigor’ev et al.), Moscow: PIN RAS, p.120–130 (in Russian) (2009).

5. Busarev V.V. Sol. Syst. Res. **36**, 39–47 (2002).

6. Busarev V.V. Spectrophotometry of asteroids and its application / LAP LAMBERT Acad. Publ. GmbH & Co. KG, Saarbrücken, 250 p. (in Russian) (2011).

7. Busarev V.V., Dorofeeva V.A., Makalkin A.B. Earth, Moon and Planets **92**, 345–357 (2003).

8. Srinivasan G., Goswami J. N., Bhandari N. Science **284**, 1348–1350 (1999).
9. Safronov V.S. Evolution of the protoplanetary cloud and the formation of the Earth and the planets / TTF-667, Washington, 206 p. (1972).
10. Safronov V.S., Ziglina I.N. Sol. Sys. Res **25**, 139 (1991).
11. Busarev V.V. Asteroids, Comets, Meteors (ACM) 2012, abstract #6017 (2012).
12. Urey H.C. Geochim. & Cosmochim. Acta **2**, 269–282 (1952).
13. Hutchison R. et al. In: Chondrites and the protoplanetary disk / Eds Krot A. N. et al., ASP Conf. Series **341**, 933–950 (2005).
14. Fedkin A.V., Grossman L. Geochim. & Cosmochim. Acta **112**, 226–250 (2013).
15. Zolensky M., Barrett R., Browning L. Geochim. & Cosmochim Acta **57**, 3123–3148 (1993).
16. Anders E., Grevesse N. Geochim. & Cosmochim Acta **53**, 197–214 (1989).
17. Pizzarello S., Cooper G.W., Flynn G.J. In: Meteorites and the early solar system II / Eds Lauretta D.S. and McSween H.Y. Jr., Tucson: University of Arizona Press, 625–651 (2006).
18. Aponte J.C., Tarozo R., Alexandre M.R., Alexander C.M.O'D., Charnley S. B., Hallmann C., Summons R. E., Huang Y. Geochim. & Cosmochim. Acta. **131**, 1–12 (2014).
19. Managadze G.G. J. Exp. Theor. Phys. **97**, 49–60 (2003).
20. Zolensky M.E., Bourcier W.L., Gooding J.L. Icarus **78**, 411–425 (1989).
21. Brearley A.J. In: Meteorites and the early solar system II / Eds Lauretta D.S. and McSween H.Y.Jr., Tucson: Univ. of Arizona Press, p. 587–624 (2006).
22. Jewitt D., Yang B., Haghighipour N. AJ **137**, 4313–4321 (2009).
23. Jewitt D. et al. ApJL **733**, L4 (2011).

Каменно-ледяные тела как возможные инкубаторы первичной жизни

В.В. Бусарев

Московский Государственный университет имени М.В. Ломоносова
Государственный астрономический институт имени П.К. Штернберга
Россия 119234 Москва, Университетский проспект 13
E-mail: busarev@sai.msu.ru

Резюме. Показано, что объектами в ранней Солнечной системе, где в течение первых нескольких миллионов лет, вероятно, возникли условия для внеземного самозарождения жизни, были каменно-ледяные тела, точнее – их недра. Распад короткоживущих изотопов (в первую очередь ^{26}Al) в силикатной компоненте вещества стал основным энергетическим источником для образования на таких телах внутренней водной среды или даже водного океана, где было возможно появление первичной жизни. Подобные ранние процессы (таяние водяного льда, возникновение водной среды, внутреннего водного океана, затем водная дифференциация и образование силикатно-органических ядер) должны были протекать на всех крупных каменно-ледяных телах Солнечной системы за границей конденсации водяного льда, в частности, в зоне формирования Юпитера. Развитие предполагаемой простейшей жизни, вероятно, начавшееся в ядрах одного или нескольких каменно-ледяных тел, выброшенных прото-Юпитером во внутреннюю область Солнечной системы, могло продолжиться на более крупных планетных телах земного типа с подходящими условиями.