"MISSING XENON" PROBLEM AND CLIMATE OF THE EARLY EARTH. A.V. Vityazev, G.V. Pechernikova and A.G. Bashkirov, Institute for Dynamics of Geospheres RAS, 38 Leninsky prosp. (bldg. 1), 119334 Moscow, Russia, avit@idg.chph.ras.ru.

The proposed here solution for the problem of Xe deficit on the Earth and Mars is based on the fact of its enrichment in comparison to other noble gases in gas hydrates and models of impact erosion at final stage of the planet formation.

The Earth state to the time of completion of its growth and problems of early atmosphere and hydrosphere are the focus of attention of many specialists on the Earth science. Theoretical models and data on short- and long-lived radioactive isotopes say in favor that collecting of the main mass by the Earth, formation of the Moon and differentiation of the Earth into the core and primitive mantle were performed for the most part to the end of the first 100 Myr after formation of the Sun [1, 2]. As for a degree of the interior degassing, masses and compositions of the atmosphere and hydrosphere at 0.1-0.5 Ga, there is a broad range of opinions from presumption that the atmosphere and hydrosphere were absent at this stage at all (naked stage) up to hypotheses for presence of a massive atmosphere similar to the modern Venerian one and containing mainly carbon dioxide. There are also intermediate models with a moderate mass of the atmosphere containing nitrogen, noble gases in modern proportions and trace amounts of CO_2, CH_4, H_2S (SO_2), H_2O. Isotopic anomalies of oldest (4.2-4.4 Ga) Australian zircons are interpreted as a hint to a sedimentoges in presence of water basins [3].

"Missing Xe problem" is an old cosmochemical problem connected to observed abundances of noble gases in the Earth's and Mars atmospheres. Taking into account for added radiogenic Ar and losses He and, to a lesser degree, Ne as a result of dissipation the contents of the noble gases are similar to the meteoritic one (so called "planetary gases") except for the ~20-fold deficit of Xe. An active search for a possible Earth's reservoir enriched with Xe in reference to other noble gases Ne, Ar, Kr has been continued more than 30 years. There were examined ices of ice caps of Antarctic and Greenland, a lot of sedimentary rocks and different experiments on possible entry of Xe into high-pressure minerals of the core and mantle were performed. The result of all the efforts appeared negative [4]. The search for a mechanism of preferred removal of the heaviest noble gas from the Earth at any stage of its evolution or, inversely, delivery of volatiles depleted with Xe did not lead to a solution of the deficit Xe problem. Great efforts mounted to solute the problem of «missing Xe» is due to the fact that if it is not hidden anywhere in the Earth reservoir then either a material with which it was admitted on the Earth differs from chondrites radically or we do not take into consideration some unusual dissipation mechanism of preferred removal of the most heavy noble gas.

Recently [5], the 20-fold excess of Xe relative to Ar was found in natural and laboratory CH_4 – gas hydrates. According to [5], the relative content of Xe in the modern oceanic (96% CH_4 + 4% CO_2) gas hydrates is 2 10^{-7} while the estimated content of carbon in the gas hydrates is 7.5-15 10^{18} g. Therefore the total content of Xe in the modern gas hydrates is 1-2 10^{13} g, that is 1% of its atmospheric abundance. As a result, this reservoir can not play a significant role in a noble gases budget at the modern Earth.

There are two facts that permit to put into consideration a supposition about quite favorable conditions for wide extension of gas hydrates in the early Earth. Firstly, it is the known evidence for a lowered (on 25-30 %) luminosity of the young Sun. Second, it is evidence for intensive degassing of the Earth's interior at the late stage of formation of the Earth, which follow, in particular, from data on ^{129}I – ^{129}Xe and ^{244}Pu – ^{132}Xe systems.

The third important fact that permits to suppose non-trivial solution of the missing Xe problem is the great inflow of falling planetesimals (with asteroid and comet sizes and compositions). A simultaneous analyses of the mentioned properties of the early Earth permits to perform preliminary estimates of possible preferred loss of Xe at the process the impact erosion of the Earth's surface with water basins, containing gas hydrates.

Below we present our estimates in the order of value in the frame of the common approach for the Earth and Mars, as well. We start from necessity to find an explanation for a loss of 10^{16} g of the Earth's Xe (that 10 times greater its content in the modern atmosphere see Figure). If Xe was incorporated into abiogenic gas hydrates (predominantly $CO_2{\cdot}6H_20$) of early Earth, it is necessary by the way to remove of the order of 10^{22} g of carbon and $1.5{\cdot}10^{23}$ g of water. The latter number is true for the case of shock erosion of cryosphere but should be increased sufficiently for the case of gas hydrates in water basins. Thus, if one supposes that bottom layers of gas hydrates in the early water basins were in a depth range of 500 to 1000 m, a part of water volumes above the layers of gas hydrates would be lost in the impact ejections together gas hydrates. A summary mass of such water volumes might be of order of mass of the modern hydrosphere. Besides, some part of water is lost at impacts on water basins which has no gas hydrates. Recall that the total mass of water in modern oceans is $1.4{\cdot}10^{24}$ g and one in the Earth crust is $0.6{\cdot}10^{24}$ g. There is ~ $4{\cdot}10^{23}$ g CO_2 bounded in carbonates of the Earth's crust. With account of a mantle carbon the summary mass of CO_2 may be of order of ~ 10^{24} g or~$3{\cdot}10^{23}$ g for carbon.

Estimates of total composition of primitive matter of planetesimals (90% of ordinary chondrites + 10% of C chondrites + dirty ice from cometary nuclei ~1%) falling on the Earth give $1.2{\cdot}10^{23}$ g for carbon and $4.2{\cdot}10^{24}$ g for water. It is left as a subject for discussions which parts of hydrogen and water were lost during the Earth accumulation and which parts are hidden in deep interiors (for water, it is an unknown contents in mantle rocks and for carbon, it is not excluded possibility to be presented in the Earth's core, as well), apart from well-known contents in the crust and atmosphere.

In correspondence to the modern theory of formation of the terrestrial planets [1, 2] we can concede that the Earth collects 95% of its mass to the moment 4.5 Ga.

Bodies remained in its feeding zone of the total mass $3 \cdot 10^{26}$ g are distributed over sizes with the probability density $n(r) \sim r^{-3.5}$ [1, 2] up to an upper limit of the size about 500 km. Roughly speaking, during the next 100-200 Myr approximately 10^{10} bodies of sizes about a kilometer, 10^7 bodies of sizes about ten kilometers and 10^3 bodies of sizes about hundred kilometers fall on the Earth.

An increase of the Earth's radius during this time is of order of hundred kilometers and summary area of the cratered surface is three order larger the Earth surface. In other words, there is repeated erosion of near-surface layers up to a depth of order of impactor diameters [6]. For the mentioned sizes, the depths of craters surpass possible depths of gas hydrates layer formation. In accordance to different crater theory estimations, the mass of matter ejected on near-earth orbits is 1-10% of the impactor mass or $3 \cdot 10^{24} – 4.5 \cdot 10^{25}$ g in dependence on the impactor velocity 10-30 km/s. It may be expected that the main losses are accounted for by volatiles CO_2-H_2O. If gas hydrates took a sufficient part (tens percents) of the Earth's surface, the order of above numbers says in favor of the pointed mechanism of the advantage loss of Xe together corresponding carbon dioxide and water losses.

We suppose that during the period under consideration 100-200 Myr the part of the Earth surface covered with the water was, in general, within the range $0 < \varepsilon_1 < 1$, and a part of a medium-deep (100 m < H < 1300 m) basins with favorable physico-chemical conditions for presence of nonorganic gas hydrates is denoted by ε_2 . (These conditions for predominant $CO_2 \cdot 5.7H_20$ are within the known range of a phase diagram of temperatures 20°C > T > −5°C and pressures 1000 bar > P > 1 bar.) An average power h of the gas hydrates layers is to be calculated on the base of a detailed analysis of gas flows from primitive atmosphere and crust, but we take it to be equal to the typical value for the modern earth gas hydrates layers, that is h= 200 м. When ε_1=0.5, ε_2=0.5 «instant volume» of the gas hydrates will be of the order of

$$V_{\text{clatrate}} = 0.5 \cdot 0.5 \cdot 4 \cdot 10^{18} \cdot 2 \cdot 10^4 = 2 \cdot 10^{22}\ \text{cm}^3,$$

and a water loss will be $2 \cdot 10^{23}$ g if an average depth of the ocean is H_c=1000 m. A surface that is equal to the earth surface becomes coated with the craters created by $N \sim 4 \cdot 10^6$ bodies of kilometer sizes during the time of order of ~ 10^5 years. In doing so, ~ $2 \cdot 10^{20}$ g gas hydrates and ~$2 \cdot 10^{21}$ g water are lost out of limits of the earth atmosphere if 1% efficiency of the escape takes a place. If we choose an average depth of the ocean H_c=500 m the water mass $2 \cdot 10^{24}$ g that contains now in the ocean and crust should be lost during 200 Myr.

For the Mars, an assumption of presence of gas hydrares layers in early cryosphere and water basins is seemed mach less unexpected in the light of the discussion about possible presence modern near-surface gas hydrates on this planet. Favorable P-T conditions for presence of gas hydrates on the early Mars are realized at depths in the range from hundreds meters at equatorial regions to kilometers at polar ones. If we accept 500 m as an equivalent thickness of the layer of gas hydrates $CO_2 \cdot 5.7H_2O$ at cryosphere (up to 1% gas hydrates), we find $5 \cdot 10^{20}$ g gas hydrates of which loss (during the first Myr of evolution) recovers the Xe deficit on the Mars.

So, data on the most ancient Australian zircons say in favor of presence of water basins at least 4.4, 4.3, 4.2 и 4.1 Ga ago. **But it does mean presence of an atmosphere of pressure no lower 6-7 mbar.** The evidence for ancient age of ^{129}Xe points to the fact that the atmosphere never disappeared completely (in the opposite case there would not be traces of ^{129}Xe, that is the product from decay of ^{129}I, in the modern atmosphere). Data on the Xe deficit are evidence for its escape while impacts into gas hydrates covers, that is, in favor of temperate cold climate. At the same time large fluctuations of temperature and atmosphere contents might take a place while big bodies impacts

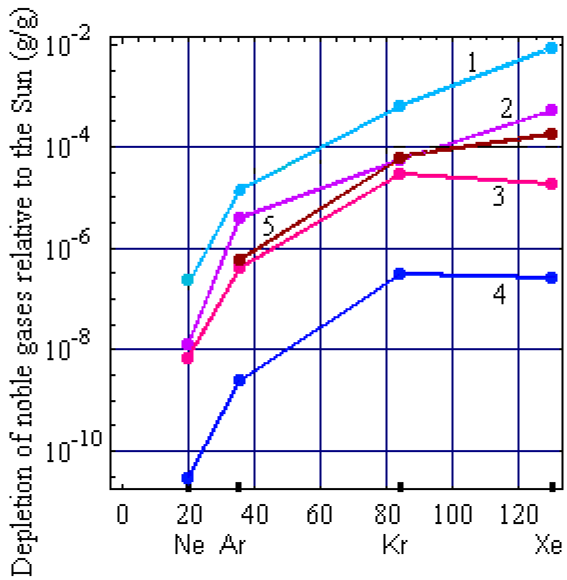

Fig. The losses of noble gases in objects of the solar system relative to their abundances at the Sun: 1 – C1-chondrites, 2 – E-chondrites, 3 –Earth, 4 – Mars, 5 – according to results of the preliminary calculations of the Earth' Xe loss together gas hydrates.

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