THE COSMOCHEMICAL LIMITATIONS ON TNE MODELS OF TITAN FORMATION

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Key words: Saturn's protosatellite disk, Titan

We have estimated a probable interval of temperature variations in the protosatellite disk of Saturn in the formation region of Titan during its accretion. For the estimation new data on the structure and composition of Titan's atmosphere, obtained with the Huygens probe [1], and the available data on he composition of atmospheres of giant planets were used. The estimates are used to reveal optimal sets of the numerical values for model parameters of the Saturn's accretion disk [2].

The work is based on two suggestions: 1) Titan was formed from the same solid material as the giant planets; 2) accretion of the regular satellites of Saturn including Titan occurred mainly by sweeping up of dust particles and small bodies [3, 4]. These particles and bodies came to the protosatellite disk of Saturn from the nearby region of the solar nebula and had time to come into chemical equilibrium with the surrounding gas before their accretion onto the growing satellite embryo. Because this equilibrium is controlled by the *P-T* conditions in the disk, we can show that the data on the chemical composition of the Titan's atmosphere allow finding upper and lower limits of the temperature in Titan's formation region (20-35 R_{Sat}).

The maximum temperatures in the Saturn's protosatellite disk can be estimated in the following way. It is experimentally found that the atmospheres of Jupiter and Saturn have several times higher abundances (relative to hydrogen) of all volatiles including the noble gases heavier than neon. In the opinion of many researches the sources of the enrichment in volatiles were icy planetesimals formed in cold regions of the solar nebula. They contained volatiles in the form of clathrate hydrates (compounds of the type of $CH_4 \cdot 5.75H_2O$, $Ar \cdot 5.66H_2O$). Nitrogen was contained as the simple stoichiometric hydrate - $NH_3 \cdot H_2O$. These planetesimals probably were main source of the gases composing the atmosphere of Titan. Therefore the temperatures in the protosatellite disk in the formation region of the satellite could not be higher than the temperatures of stability of the highest-temperature compound found in the Titan's atmosphere. From the direct measurements in the atmosphere of Titan [1] it was stated that the molecular nitrogen prevails there. Its most reasonable source the compound is $NH_3 \cdot H_2O$. Consequently, there are precisely the temperatures of stability of ammonium hydrate that can be accepted as the estimate of the maximum temperature in the disk of Saturn in the Titan formation region.

According to the experimental data [5, 6], the ammonium hydrate is formed in the temperature range from 90 to 80 K (at pressures from 10^{-6} to 10^{-7} bar). The estimates are obtained in suggestion that the whole of nitrogen is in the form of NH_3. If to admit that in the protosatellite disk of Saturn the ratio $N_2/NH_3 = 10$, that is the same as in the solar nebula [7], than it may be from the above results concluded that $NH_3 \cdot H_2O$ remained stable in the conditions of the protosatellite disk up to the temperatures $T \approx 90$ K at $P \leq 10^{-6}$ bar and $T \approx 100$ K at $P \leq 10^{-4}$ bar.

The minimum temperatures in the protosatellite disk of Saturn are much more difficult to be estimated uniquely. It is experimentally stated that xenon is absent in the atmosphere of Titan and the abundance of methane decreases with distance from its surface. From this fact one may suggest that formed in the solar nebula xenon clathrates as well as methane clathrates (very similar in formation *P-T* conditions), were thermally destroyed in the Saturn's disk. It is suggested that the main source of carbon in the atmosphere of Titan are the organic compounds similar to that found in comets [8]. In this case for the lower limit of temperatures we can adopt the temperatures of stability of methane clathrates and xenon clathrates that, according to [6], should be higher than 60 K at $P<10^{-6}$ bar and > 70 K at $P \leq 10^{-5}$ bar. These estimates of the lower limit of temperature in the Saturn's disk for the formation zone of Titan appear presently most probable.

At the same time it is necessary to point to the existing alternative variant of estimation of the lower limit of temperatures in the subnebula of Saturn. If clathrate hydrates of methane and xenon entered into composition of Titan, but for some reasons did not entered into its atmosphere, than the minimum temperature in the protosatellite disk of Saturn in the region (20-35 R_{Sat}) can be presumably estimated from the following fact. In the atmosphere of Titan only traces of the primordial argon were detected with molar fraction of ^{36}Ar of $(2.8 \pm 0.3) \times 10^{-7}$ [1], whereas the atmosphere of Jupiter is enriched in it three times relative to the solar proportion. In this case, in order to argon clathrate to be thermally destroyed, the minimum temperature in the Saturn's disk in the Titan formation region should be ≥ 40 K. Hence for this case the temperature interval 40-60 K at $P \leq 10^{-6}$ bar and 45-65 K at $P \leq 10^{-5}$ bar can be taken as the lower temperature limit. Further experimental researches will allow its more confident estimation.

Conclusion: From the present-day cosmochemical data on the composition of atmospheres of Jupiter, Saturn and Titan it may be inferred that the temperatures in the protosatellite disk of Saturn in the formation region of Titan (20 - 35 R_{Sat}) during its accretion period were probably higher than 60 - 70 K and lower than 90-100 K at $P = 10^{-7}$-10^{-5} bar.

The work was supported by the Russian Foundation for Basic Research (Grant 04-05-64867).

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Electronic Scientific Information Journal "Herald of the Department of Earth Sciences RAS" № 1(24)'2006
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2006
URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2006/informbul-1_2006/planet-1e.pdf

Published on July, 1, 2006