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The thermal history of Enceladus consistent with the chronology of the Saturnian system

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Abstract

Recent volcanic eruptions on Enceladus imply that it should have a liquid reservoir inside, producing the plumes. The differentiation onto a rocky core (radius 150-160 km) and ice mantle (thickness 90-100 km) needed $T \geq 173$ K and plume composition (presence NH_3) needed $T \geq 500$ K [1].

We suggest that the role of different heat sources in geologic activity of Enceladus must be reconsidered. The sources are: the radiogenic short-lived isotope ^{26}Al often supposed to be the most important one (at the initial $T \sim 200 - 220$ K), the long-lived radioactivity and the tidal friction (the last two ones presumed as less effective) [2-5]. We present arguments against any significant role of ^{26}Al and against initial "warm" conditions, and suggest that long-lived radioactivity and the tidal friction acting throughout the history of Solar system could be responsible for modern state of Enceladus [6].

1. The chronology of the Saturnian system

Enceladus cannot be considered as a first generation body of the Solar system that formed in time interval $(1\text{-}3)\times10^6$ yr after the solar nebula had received the short-lived isotopes. Enceladus belongs to the system of regular satellites which formed obviously after Saturn itself. In modern theories the origin of giant planets (in our Solar system) had two main steps [7]. First, the cores of condensable matter had been accumulated, and second, a core-nucleated accretion of the nebula gases completed the formation of planets.

The accumulation of the Saturnian core (10-20 $M_\oplus$) takes time about 10^7 yr even with the account of runaway growth (i.e. the possible acceleration of process) [8]. The satellites had been formed in saturnian gas-dust accretion disk on last stage of planet's growth (otherwise they would fall onto the planets). The disk must have had the present orientation of Saturnian equatorial plane inclined $26^o.7$ toward the main plane of the solar nebula. This tilt resulted from an oblique impact of a protoplanetary body of $\sim 5\ M_\oplus$ [9]. The formation of such impactors in the solar nebula also needed a long time. It must be concluded that at time of Enceladus formation all ^{26}Al (half-life period $\sim 7\times10^5$ yr) was already fully decayed.

Another argument against the heating of Enceladus by ^{26}Al may be the absence of volcanic activity on other small and medium-sized satellites of Saturn. Thetis, Diona, Rhea and Iapetus are many times more massive than Enceladus and nevertheless show only some tectonic features on surfaces. If they had such an effective source as ^{26}Al in early time, they would be heated, differentiated and more geologically active. However the largest (after Titan) satellite Rhea has so high value of moment of inertia C/MR^2 (namely 3.9 or 3.7), that may be considered as a non-differentiated body [10, 11].

The early heating of protosatellite matter up to 200-250 K on Enceladus' orbit could have place [12] but all data on chemical composition of this satellite (ices H_2O, CO_2, and $NH_3{\cdot}H_2O$) are in favor of lower temperatures – about 90 K. At last, the complex structure of Saturnian system manifests consequences of many collisions between the satellites and impacting bodies from circumplanetary and circumsolar orbits.

Possibly that all satellites inside Titan orbit were not only bombarded by crater-forming bodies but also destroyed and re-accumulated several times [13]. If that process was real, then short-lived radiogenic isotopes could not play any role in heating bodies for every chronology.

2. The long-enduring sources of heat

We have evaluated [6] that in course of ~ 3 Ga (~ 3×10^9 yr) the long-lived elements U, Th, ^{40}K, concentrated in the silicate fraction of the satellite, could give internal temperature rise > 100 K, melt ices, form its iron-silicate core and semi-liquid mantle. Further heating in last 1 – 1.5 Ga might be due to tidal friction. We have used the same formula by [14] that was applied in forecasting Io's volcanism. The total energy of tides is comparable with that of radioactivity in 3 Ga. If this energy were concentrated in limited region inside the mantle it could give a temperature rise of several hundred K. It is well known that on Earth the dissipation of tidal energy is extremely non-uniform. We have used the value of rheologic parameter $\frac{k_2}{Q} \approx 10^{-3}$ in view that such value is in agreement with the synchronization of axial rotations of satellites (especially the most distant regular satellite Iapetus) within the history of solar system. It may be noted that we used the modern value of the eccentricity of Enceladus' orbit (0.0045), the tidal friction leads to circularization of satellite orbit, so in the past, with eccentricity greater than its present value, the effect should be more pronounced [6].

6. Summary and Conclusions

We concluded that significant role in Enceladus thermal history played the combination of two factors: long-lived radiogenic isotopes and the tidal friction.

Acknowledgements

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