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Tectonics of Enceladus and hypotheses of Proto-Enceladus

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Abstract

We consider here the hypotheses of proto-Enceladus stating the initially Enceladus, a satellite of Saturn, was a considerably larger body. Presently, every second ~200 kg of the satellite's mass is ejecting into space from the South Polar Terrain (SPT). If it is an average rate then initially Enceladus was ~30% larger. We have found many indications that support this hypotheses.

1. Introduction

Enceladus, a satellite of Saturn, is the smallest celestial body in the Solar System where volcanic activity is observed. Every second, the mass of ~200 kg is ejecting into space from the South Polar Terrain (SPT) [1]. This rate corresponds to the following rates of decrease: radius - 9 m My^{-1} (per million years), surface area - 50 km^2 My^{-1} - [2, 3].

The size of the satellite directly after accretion (we refer to this body as proto-Enceladus - [3]) is unknown. It can be estimated in two ways. First, if the average mass outflow is equal to the present rate then the satellite's original mass was ~30% bigger than today. Second, we assume here that density of proto-Enceladus was equal to the present density of Mimas because they were formed in the same part of the nebula. Both approaches give similar results. The initial radius of proto-Enceladus was 296 km (compare with the present 252 km), initial mass 1.25×10^{20} kg (present 1.08×10^{20} kg).

In the present research we consider the consequences of this hypotheses. It is an extension of papers [2] and [3].

2. Subsidence of SPT and tectonics

The loss of matter should lead to global compression of the crust. Typical effects of compression are: thrust faults, folding, and subduction. However, such forms are not dominant on Enceladus. It could be explained if the main tectonic process is the subsidence of South Polar Terrain (SPT) – see [2, 3].

The volatiles escape from the hot region through the fractures forming plumes in the space. The loss of the volatiles results in a void and motion of solid matter into hot region to fill the void *in statu nascendi*. The motion includes: (1) subsidence of SPT; (2) flow of matter in the mantle towards the void; (3) motion of plates adjacent to SPT towards the active region. If emerging void is being filled by the subsidence of SPT only, then the velocity of subsidence is ~0.05 $mm\cdot yr^{-1}$.

3. Tidal heating and stability of the active region

Present total heat flow from SPT is at least 5.8±1.9 GW, while the present radiogenic contribution is only 0.3 GW = [4, 5]. Tidal heating in a homogenous satellite is given by the formula [1]:

$$q_{t\_av}=63r^4n^5e^2/(38mQ) \qquad (1)$$

where q_{t_av} is the average power per unit mass of satellite, ϱ is the density, r is the satellite's radius, n is the mean orbital motion, e is the eccentricity of the satellite's orbit, Q is the dimensionless dissipation factor, and m is the shear modulus of the satellite's interior. The most reliable estimation of tidal heating is probably based on Q for Saturn. With Q_{Saturn} ~18000 it gives 1.1 GW as an upper bound [5]. If this value is correct, then the satellite releases the energy stored in an earlier epoch. However, it has recently been suggested that Q_{Saturn} could be lower [6] (1500-2000), and consequently present power of tidal heating could be considerably higher. If this value is confirmed, then we can expect that the net heat loss of Enceladus is lower.

Parameters Q and m decrease with increasing temperature T (e.g. close to the melting temperature they are very low), so the tidal heating is increasing with T leading to additional increase of T. This strong positive feed-back could result in concentration of tidal dissipation in time and space -

[7, 8, 9]. The present volcanic activity is concentrated in SPT.

4. Past and future active regions

Some facts indicate that the activity in SPT is now decreasing, e.g. one tiger stripe (Alexandria Sulcus) is already less active. Moreover the arcuate shape of SPT perimeter indicates that subduction lasts for a long time. Compressive forces from adjacent plates tend to close the vents.

There are also other observations suggesting that activity centers are not permanent. In a few places on Enceladus, remnants of active centers are observed. We suggest that the whole region bounded by Sarandib Planitia and Diyar Planitia and extending to Hamah Sulci in the north is a remnant of an ancient center of volcanic activity similar to the present SPT. In this region, a few structures are indicated that could be relics of structures typical for an active region [1].

The indication of the future activity centers is less certain. However, the ovoid-shaped depression up to 2 km deep, of size 200×140 km with the center at 200E, 15S is a good candidate. The depression boundary is uncorrelated with any geologic boundaries [10, 11], so it is probably a result of recent internal processes like widespread melting of ice at the core-mantle boundary. The energy involved in this process is large, so substantial surface effects in the future are possible.

Note also that we do not know the present age of the satellite surface. Age assessment depends on the assumed model of the flux of meteorites. For the lunar-like flux, cratered plains of Enceladus are 4.2 Gyr old, and only 1.7 Gyr old, if cometary impact rates are used [1, 12]. If ‘cometary’ chronology is correct then we have no data concerning 2/3 of Enceladus history. During that time there could be a number of activity cycles, and the total decrease of the surface area could be 300,000 km^2.

5. Summary and Conclusions

If our hypothesis is confirmed, then Enceladus will be an exceptional body, possibly representing a new class of celestial bodies: bodies decreasing as a result of endogenic activity.

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