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Enceladus: starting hydrothermal activity

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Abstract

We describe a process for starting the hydrothermal activity in Enceladus' South Polar Region. The process takes advantage of fissures that reach the water table, about 1 km below the surface. Filling these fissures with fresh ocean water initiates a flow of water up from an ocean that can be self-sustaining. In this hypothesis the heat to sustain the thermal anomalies and the plumes comes from a slightly warm ocean at depth. The heat is brought to the surface by water that circulates up, through the crust and then returns to the ocean.

1. Introduction

Little Enceladus is the most amazing of the icy satellites. It is the sixth-largest moon of Saturn, but at 500 km in diameter, was thought to be much too small to be geologically active today. However, its South Polar Region exhibits erupting plumes and numerous thermal anomalies that radiate a total of ~15 GW of power [1]. These anomalies have local "hot" spots where temperatures can be as high as one hundred degrees hotter than is possible by heating with absorbed sunlight. Furthermore, analysis of some of the tiny ice crystals in the plumes found salts. This discovery led Postberg et al. to conclude that these particles came from "sea water"[2]. The circulation hypothesis is illustrated in Fig. 1, which schematically depicts the ongoing process of water circulation in the crust below the active areas. *The ocean:* At the bottom, callout #1, the figure indicates a subsurface ocean. This ocean has dissolved in it all of the chemical species observed in the plumes. It underlies the South Polar Region but its overall size is not known. The ocean is assumed to be at a temperature several degrees above the eutectic for ice and seawater. Obviously, to maintain this temperature the ocean must have a source of heat or it will freeze on a time scale of ~30 million years [3]. That source of heat is unknown. *Rise of water:* At #2 the ocean water is proceeding upward toward the surface and has reached the depth where the pressure allows dissolved gas to come out of solution. The gas is primarily CO_2 [4]. The upward going column is now a bubbly mixture. The bubbles make the water buoyant and this allows it to reach the surface. Without the bubbles the seawater would be able to rise only ninety percent of the distance to the surface. Near the surface it spreads out beneath a (perhaps flash frozen) lid of ice. *Plume chamber:* At #3 some of the water is entering (or passing through) a plume chamber. It replenishes the chemicals that have

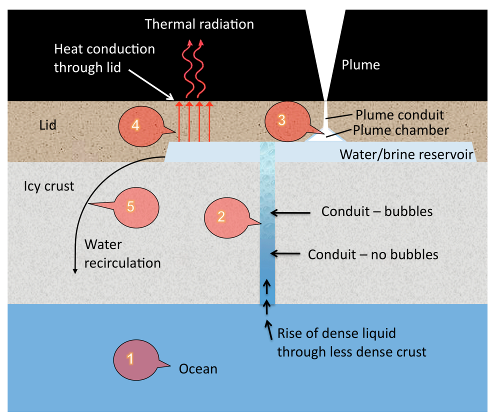

Figure 1: Not-to-scale sketch illustrating the hypothesis of ocean water circulation.

erupted as well as the heat that powers the process. The plumes erupt (in total) about 150 to 300 kg sec^{-1} [5]. About 0.5 GW of heat is used in the plume chambers to volatilize the plume gases [6]. For the internal workings of the plume chambers we have adopted the model of Schmidt et al. [7] and refer the reader to that paper for details. *Surface heat loss:* At #4 is a symbolic thermal anomaly. Most of the upwelling seawater is needed to replenish the ~15 GW of heat that is radiated by the surface. *Recirculation:*

At #5 the water is indicated as returning to the ocean via fissures or cracks (not shown) in the icy crust. The surface in the South Polar Region shows evidence for many present and past fissures in the surface.

2. Initiating the Circulation

If ocean water is moved upward, then gas will come out of solution and bubbles will form. Tidal stress can start this process by fissuring the ice crust deep enough to penetrate into the water table. On Enceladus, coherent ice can maintain an open fissure to a depth of about 1.5 km. With a 10 km thick crust, bubble-free seawater rises to 1 km below the surface. If a fissure opening extends deeper than this, then void space can be created and water can pour into it. To restore the water table, fresh ocean water rises up the conduit and bubbles form. A strong point in favour of this process is that it is recurring due to periodic fissuring [8]. Thus, ongoing hydrothermal activity can terminate and a new activity can start elsewhere, or even the old site could be restarted if the fissure reopened.

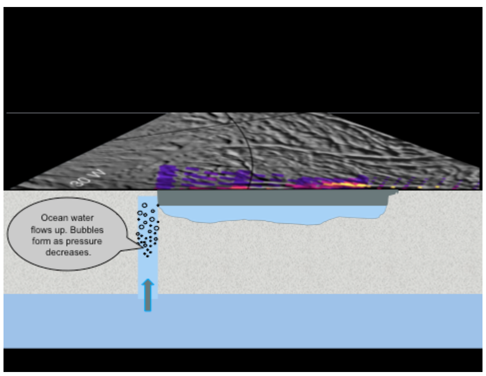

Figure 2: Fissure filling with ocean water. For sustained circulation, water returns to the ocean via cracks and fissures (pathways not shown).

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