THERMAL PALIMPSESTS ON EUROPA: HOW TO DETECT SITES OF CURRENT ACTIVITY.

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Introduction: The prospect of a global ocean beneath Europa's ice shell has caused considerable excitement [1,2,3], not the least because of the exobiological possibilities. The surface observed by Galileo shows features reminiscent of water volcanism [3] and diapiric eruptions of warm ice [4]. Large regions of chaotic terrain indicate that warm, mobile material (perhaps liquid water) disrupted the surface [1] , while the resurfacing age of the surface -- based on a survey of the impactor environment of the Galilean satellites in the present time -- could be as young as 10 Myr [5]. However, no firm conclusion can be now be drawn as to whether a global ocean currently exists at depth; most surface features can be also be explained by warm, viscous ice beneath a brittle shell, or by isolated melt pockets of water or brines in a solid ice shell [3]. In addition, the stratigraphic youth of chaos and diapir structures, compared to that of the ridged plains, remains to be explained in a steady-state model of a Europa ocean overlain by brittle ice, and holds open the possibility that the surface is ancient and inert after all [3].

We propose thermal remote sensing as the best method for determining whether resurfacing is occurring at the present time, whether in the form of relatively plastic ice near its melting point, as an ice-water slurry, or as liquid water. The nominal Europa surface age of 10^7 yr implies a resurfacing rate of ~1 km^2/yr; therefore, a 1-10 km^2 resurfacing patch size would imply 1-100 icy eruptions each century.

Detection of these hot spots, which we call thermal palimpsests, will enable the selection of the most interesting areas of Europa for future lander and penetrator missions: those areas where material has been brought to the surface from the ocean, or from pressurized cryovolcanic reservoirs. Thermal detection of erupted water or warm ice would also allow the geological style of resurfacing and so the nature of Europa's landforms to be inferred. Specifically, if Europa possesses many thermal palimpsests, their identification would allow determination of which types of geological landforms are active today, the dimension and configuration of resurfacing patches, and the global distribution of cryomagmatic activity. If Europa possesses few thermal palimpsests, identification of these few areas of current activity would be vital to successful future landed exploration of Europa. Finally, if there is biology on Europa, its most well-preserved traces would more likely be found at the youngest (hence warmest) surface extrusions.

The method we used to estimate how long features would be thermally detectable is to extend Howell's [6] study of Ionian volcanism to the radiative cooling of a solid slab of ice, or of an ice crust forming over liquid water (the radiative Stefan problem). The extrusion cools with a radiative upper boundary condition and a temperature difference between the melt (if any) and the surface which varies continuously during cooling, freezing, and equilibration with solar insolation. For simplicity, we assume the surface is bare ice, a sintered high-density frost, or a low-density frost whose time constant is much shorter than the cooling time of the extruded ice slab or ice crust forming over the body of liquid water. A schematic diagram of the problem is shown in Figure 1. We derive analytic expressions for the cooling rate of a slab and of an ice crust over liquid water. Our cooling slab result agrees with the long-time limit of Chambre's [7] analytic series solution of the nonlinear Volterra integral equation for this problem. Our Stefan result agrees with Howell's numerical model for silicate and sulfur volcanism. Our model accounts for latitude where Europa's obliquity may be neglected (<= 75 degrees), and accounts for diurnal effects if the frost over the ice is thermally thin. We present contour plots of the ratio of endogenic to insolation heat flow, averaged over a diurnal cycle, as function of latitude and time, for the cooling solid slab and freezing ice crust cases. We define a detection limit as the time when endogenic and insolation heat flows are equal.

We find that a polar-orbiting spacecraft with visible and infrared imagers could detect, at the Europan equator, bodies of warm ice extruded ~30 yr ago, or water bodies which began refreezing up to ~100 yr ago, if those bodies are at least 200 m in diameter. The extrusion cools more rapidly at high latitudes, but the detection limit drops more rapidly with latitude so as to increase the time over which ice freezing over a water body is detectable to ~400 yr, as shown in Figure 2. We conclude that thermal remote sensing is more capable at detecting recent change on Europa's surface than other remote-sensing methods.

References:
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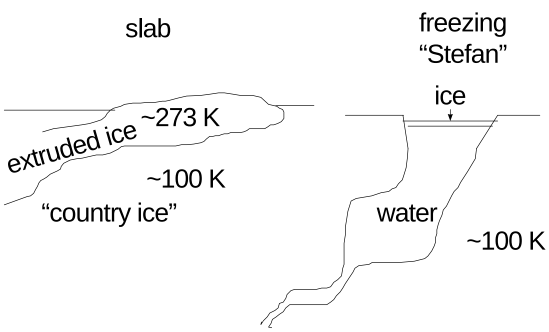

Figure 1: Schematic diagram of the problem. On the left, the extruded solid slab. On the right, a crust of ice freezing over a body of water. Cooling is by thermal radiation to space at the surface; the bodies of warm ice or water are assumed large enough that conduction through the sides of the extrusion is negligible.

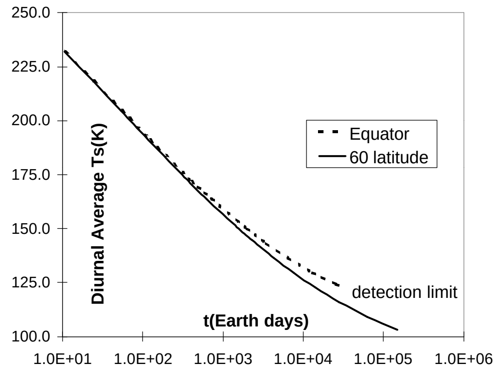

Figure 2: Diurnal-average surface temperature T_s as a function of time for an ice crust freezing over a water body at the surface of Europa, at the Equator and at 60° latitude. An initially solid slab of ice (not shown) cools about three times faster than an ice crust forming over water. The ice cools more rapidly at high latitudes, but the insolation temperature falls even more rapidly so that the thermal palimpsest remains detectable for a longer time at a higher latitude. The cooling curves end at the detection limit, which we define as the time when endogenic and insolation heat flows are equal. At the Equator, the detection limit is ~100 yr; at 60°, the detection limit is ~400 yr. An albedo of 0.6 is assumed.