Is Tyre Macula an Ice Cauldron?; Constantine Thomas, Environmental Science Division, I.E.B.S., Lancaster University, Lancaster LA1 4YQ, England, c.thomas1@lancaster.ac.uk

Tyre Macula is a large, dark circular feature on Europa, classified first by Lucchita and Soderblom [1] as a "Class 2" impact feature similar in nature to the crater palimpsests on Ganymede. It lies near the junction of several dark lineaments, and exhibits several features that throw doubt on an impact origin. Here I propose that Tyre Macula is actually a large Ice Cauldron - a feature created by local ice subsidence as a result of subsurface geothermal heating on Europa.

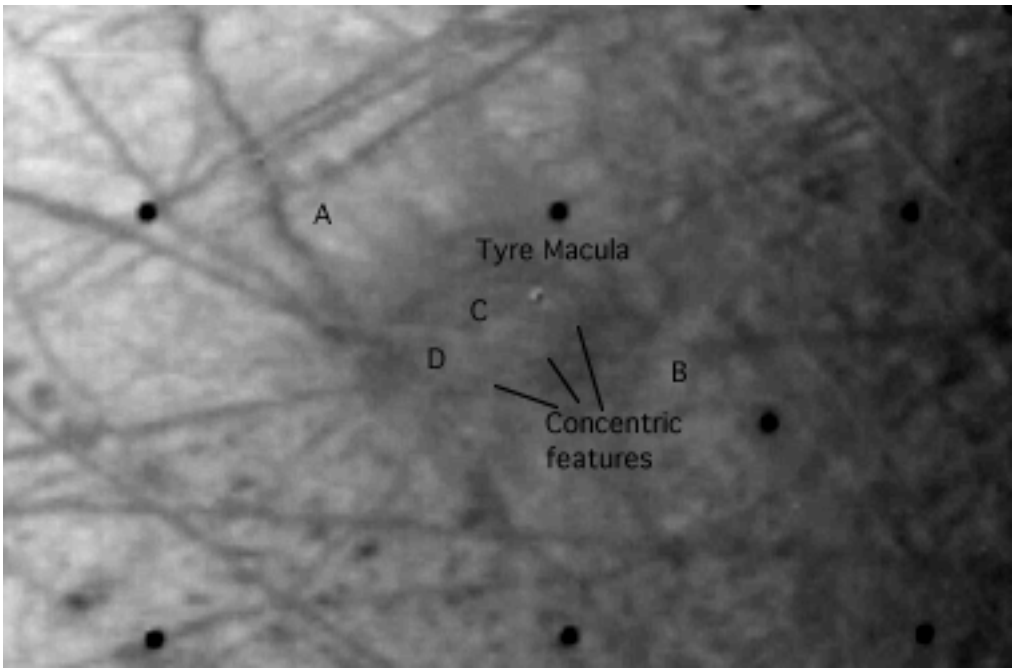

Figure 1: Tyre Macula (Voyager image c2064910, Magnification x2, Histogram Stretch)

Tyre Macula is the dark circular feature shown in Figure 1 and is approximately 120 km in diameter. It is cut by a wide dark ridge (**A**) striking north-south and appears to overlie another dark lineament (**B**) that strikes from east to west. A circular structure (**C**) is visible in the centre that appears (based on brightness variations within it) to be a bowl-shaped depression approximately 20 km in diameter - the small circular 'feature' to the north-east of this is actually an imaging artefact and not a geological structure. A small bright lineament (**D**) crosses Tyre Macula from west to east, and may be related in origin to lineament **B**. The time sequence to be interpreted is therefore that Tyre is intermediate in age between Ridge **A** and Lineaments **B** and **D.** Lucchita and Soderblom [1] also identified concentric structures within Tyre Macula that are visible and labelled in Figure 1. There appear to be three main regions comprising the feature - a slightly brighter central region 60 km in diameter is surrounded by a sharply defined darker ring that describes the accepted external circumference of Tyre up to a diameter of 120 km, and a tenuous fuzzy halo that extends beyond this to a diameter of 190 km.

The morphology of Tyre Macula is distinctly unlike that of the Ganymedean palimpsests to which it is compared by Lucchita and Soderblom - those palimpsests do not possess central bowls, there is more internal structure visible in Tyre, and the feature itself is much more sharply defined. These differences lead me to the conclusion that Tyre Macula is not a palimpsest, while the features described above imply that it was formed by some hitherto unrecognised endogenic process.

The appearance of Tyre Macula is similar to that of **Ice Cauldrons** found in terrestrial domains that are both volcanic and ice-covered, except on a much larger scale. On Earth, Ice Cauldrons such as those located in Iceland vary in size from several hundred metres to a few (< 10) km across and are up to 200 metres deep. While no definite correlations between diameter, depth and thickness of ice sheet have been noted so far, the larger ones do appear to be deeper and are situated on thicker glaciers.

Ice Cauldrons are large circular features found on some glaciers that overlie volcanic terrain. They vary in appearance, but most consist of a central unfractured depression surrounded by an extensive ring of concentric and eccentric fractures, the separation of which increases radially with distance from the centre [2]. At least some Ice Cauldrons on Earth are temporary features, disappearing as a result of ice creep and snow cover.

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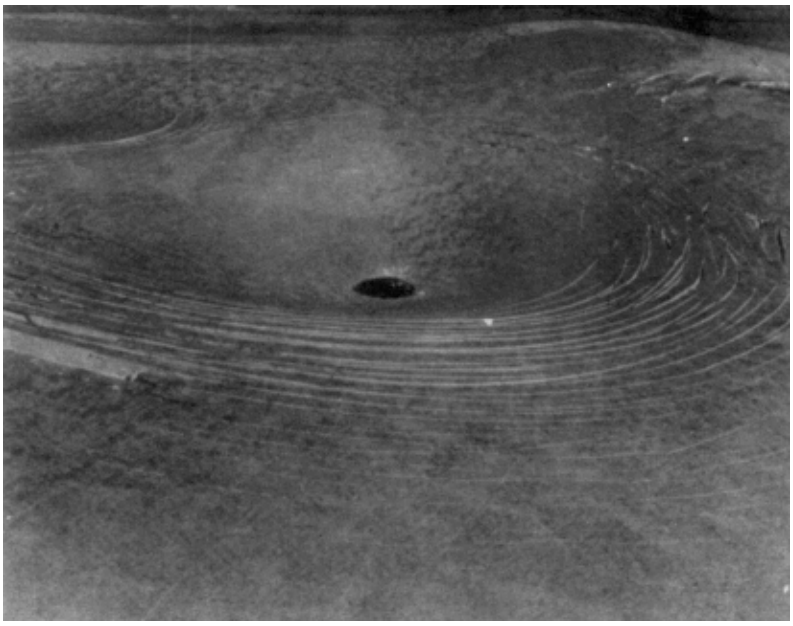

Figure 2: An Ice Cauldron in Iceland (C.A. Wood, 1980 [2])

On Earth, Ice Cauldrons such as the one shown in Figure 2 form through subsidence caused by subglacial heating. Ice is melted by localised geothermal heating to form a dome-shaped reservoir of water at the base of the glacier. Eventually, the water pressure exceeds the ice overburden pressure and the water bursts forth from under the glacier, causing a glacial flood. The glacier then sags rapidly into the void left by the water, creating concentric fractures in the ice through sudden brittle deformation [2]. No examples have been noted on Earth where the water has been extruded via the fractures - it always escapes from elsewhere along the base of the glacier - though in Figure 2 a small lake is visible in the centre of the structure which formed as the sinking glacier intersected the water table.

Europa is believed to have suffered extensive tidal heating as a result of the orbital evolution of the Galilean satellites. Most current (pre-Galileo) models assume the presence of a thick ice layer on the surface overlying a silicate crust, with the possibility of a transient or local liquid water ocean maintained at the boundary by tidal heating. Here however, I assume that no subglacial ocean was present at the time Tyre Macula formed, so that the ice and silicates would be in direct contact in this region.

I propose that heating from igneous intrusions or a volcanic eruption beneath the ice could have led to the formation of an Ice Cauldron at Tyre Macula by the mechanisms described earlier. Since there is no lateral edge to the planet-wide ice sheet, I suggest that a fracture was created in the ice above the pressurised reservoir of meltwater that allowed the water to escape at the surface in the centre of what would become Tyre Macula; as the water escaped from the ice/silicate interface, the overlying ice collapsed to form an Ice Cauldron. The darker albedo of Tyre Macula would therefore be the result of 'dirty water' escaping to the surface and covering the area.

The sequence of events would occur in this scenario as described here: A meltwater reservoir was created at the base of the ice layer by geothermal heating in the silicate crust. When the fluid pressure exceeded the ice overburden pressure, a fracture propagated upwards to form a vent above the reservoir and allowed the water to break through to the surface. Water flowed radially outwards from the vent until the supply was exhausted, whereupon the diameter covered by the flow was approximately 120 km. Assuming a flow thickness of about 30 m, this requires a volume $\approx$340 km^3 of erupted water, corresponding to a minimum reservoir radius (assuming a hemispherical reservoir) of just under 5.5 km. The central region then rapidly collapsed to create the central bowl. The reservoir is similar in scale to the observed radius of what I interpret to be the central bowl-shaped depression; transmission of the stresses through a thick ice sheet could explain the difference in size between the reservoir and the bowl. However, I suggest that the attendant wreath of fractures only extends to the edge of the bright central region at a radius of 30 km, since fracturing would expose brighter ice below the 'dirty water' veneer and thus increase the local albedo. Finally, the water froze as it flowed over the surface, and the resulting ice frost settled around the exterior to form the fuzzy halo around the entire structure.

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References: [1] Lucchita B. K. & Soderblom L.A., *Satellites of Jupiter*, 521, 1982. [2] Wood C.A., Ice Cauldrons and Basins in Iceland and on Callisto, *Conference on Multi-Ring Basins (Formation and Evolution)*, 118-120, 1980.