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Frozen Seas as part of Mars's Ecosystem

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Introduction

The creation of lakes and seas by flooding occures rarely on Mars, but can still be significant for the planet's ecosystems supposing that terrestrial-like polar and permafrost micro-organisms are present. Connections of such isolated environmental niches to the planet as a whole is necessary. Meteorite impacts provide one linking mechanism – on the kyr to Myr timescale. We consider the freezing of lakes generated by subcrustal outflows or large bolide impacts and the subsequent evolution of these formations via sublimation and meteorite impact, to assess how associated life-forms might retain viability and spread to other habitats. Analogous life and impact dispersal in sun-facing slopes in cliffs on the north polar cap was studied in [1].

Surface seas and impact lakes

Recent Mars missions have confirmed the long-suspected presence of H_2O in relic seas [2] and ground-ice [3]. Mars Express sent back dramatic pictures of "pack-ice" in flat terrain and of flooded craters in the frozen Elysium Sea [4]. Crater counts show a very young (~5 Myr) surface, which implies deep reservoirs of water that flood out episodically in the current epoch. The presence of near-surface ground-ice, predicted to be in quasi-equilibrium with atmospheric water, has been confirmed by Mars Odyssey as widespread at high latitude ($\geq 60^o$) [5].

The Elysium Sea was presumably formed by a flood of water whose surface rapidly froze. Erratic flow or tidal disturbance then broke up the initial ice, followed by drifting that created the pack-ice structure [4]. Dirt within the water/ice is left on the surface as the ice sublimates ("sublimation lag'') and further wind-blown dust adds to the surface layer. Once this forms a stable covering, the diurnal T would be little different from Mars's regolith, range 190–250 K. With the estimated lifetime of 5 Myr and sublimation loss of 30m [4], the dirt-dust layer must have grown thick enough to choke off most sublimation (to ~5 µm/yr), presumably via its diffusion-blocking as well as thermal insulating properties [3].

A lake may be formed in the base of an impact crater in a frozen sea or ice dominated terrain, because the impact melt water cannot drain away into the frozen ground, but tends to seal cracks in it. Hydrocode modelling [6] finds incipient melting in unexcavated material extending below much of the crater. The crater size depends primarily on the size and energy of the impactor, but also on H_2O content, porosity etc. For concreteness, take a 10 m deep, 100 m radius lake at base of a 1 km crater (over 90% of impact energy goes into ejecta [7], ~1% goes to melting the ice).

Once the water cools below 4^oC, the water with suspended dirt freezes rapidly. Water vapour sublimates from the upper surface and leaves a thickening layer of dust or dirt behind. We solve the conduction and energy balance equations over the diurnal cycle for a two-layer water/ice/dust model. The latent heat of freezing delays ice formation and the dirt layer thickens with time.

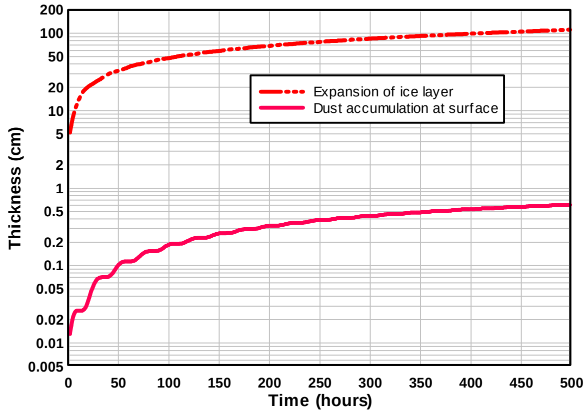

Fig. 2 Profiles of thickening ice with accumulating dirt (as sublimation lag) on a lake formed by flood or impact from [8], following the initial cooling of the water to below 4^oC. The ripples seen at <100 hours in the dust/dirt thickness reflect the diurnal cycle.

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Results given in Fig.1 [8] (assume a fraction ~10% dirt in the ice) show that the ice freezes to a depth of ~1m in twenty days, because the dust layer under 1cm thick is thermally insulating as well as acting as a buffer against diurnal heating. Freezing of a 10m deep lake or sea takes ~2 martian years on this model, though the complexities of sedimentation in the lake, dust storm deposits and dust inhibition of vapour diffusion need to be taken into account. If dissolved salts depress the freezing point, the time-scale is extended.

Environments for ice-based life

Microbial *extremophiles* are ubiquitous in terrestrial ices - psychrophilic and psychrotrophic archaea, bacteria, fungi and algae are dominant life-forms of the Earth's icy brines, cryoconite ecosystems as inclusions in ice, ancient permafrost and the arctic/antarctic Polar caps [9] so good candidates for life in martian ices, as well as in comets and icy moons of Jupiter and Saturn. There is evidence for reproductive life down to 230K and some metabolism even lower [1]. H_2O with extracellular bio-polymers tends to be mobile on interfaces. Metabolism and replication at low temperature is very sensitive to the actual temperature, and increasingly slow below 230K (~exp{-A/T}, $A \approx 10^4$K). Thus micro-environments warmed for limited times could be the most significant. The Elysium Sea is near equatorial and surface-warmed to ~250K around midday, so psychotrophic organisms could live in the dirt layer, reactivate metabolically under the midday warming pulse and take advantage of vapour from the slowly sublimating ice, while protected from harsh UV conditions by the cm-scale crusts.

Impacts dispersing life and nutrients

In default of tectonic and volcanic activity (the last volcanic lavas are ~100 Myr old), meteorite and bolide impacts are a significant geological agency. Meteorite **i**mpact cratering rates come from lunar data scaled to Mars, with account for its thin air decelerating and fragmenting small impacters [10]. This limits the power law to crater diameters $\Delta >$ 10m and gives a functional fit

$$\Psi = 1.5 \times 10^{-12}\, \Delta^{-3.1} \quad / \mathrm{km}^2.\mathrm{yr}$$

craters > Δ, values of Δ = 10m to 100m.

Incoming meteorites >1m in size penetrate the thin martian atmosphere and their impacts fragment rocks and overturn surface soils, effectively 'gardening' the ice-dust regolith. The smallest impacts, with craters ~10m across and ~3m deep, break through the ~10 cm dirt crusts and eject fragments to a few tens of metres. Thus mobilised, the micro-organisms can be carried by winds to new potential habitats.

Km-sized cratering events are appropriate to the 10-100 kyr scale [1] and cause ejecta to be distributed regionally (few 100km scale). Their impact melt-water could be locally contained if impacts are into km-deep frozen oceans or ground-ice, The 1 km craters might retain liquid water for years only, but their 10m thick ice under dirt crust could persist for Myr, as inferred in the Elysium Sea.

Impacts into relic seas (or permafrost at latitudes above 60^o) would eject microorganism-bearing fragments of subsurface ice into a hostile and highly desiccated new environment. Protection within soil and 'stones' and a covering of dust or frost would give a chance of survival. The rare impacts of km-size bolides offer other prospects in that the vapour plume blows through the atmosphere ejecting fragments over planetary scales, these potentially landing in relatively friendly polar habitats.

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