OBSERVABLE EFFECTS OF POST-IMPACT HYDROTHERMAL SYSTEMS INCORPORATING FREEZING.

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Summary: Post-impact hydrothermal systems subjected to mars-like surface temperatures (-53°C) and reasonable surface permeabilities (10^{-10} m^2) produce flow patterns with spatially diagnostic, surface-exposed water-to-rock (W/R) ratios of ~1000, channel-carving surface discharge rates of ~1 m^3/s and lake-forming total discharges of ~10^{12} m^3. A bolide 3.9 km in diameter traveling at 7 km/s generates a 45 km crater and delivers enough energy to heat subsurface water, and drive hydrothermal circulation (figure 1). This post-impact hydrothermal (PIH) circulation can lead to surface discharge of water, and chemical alteration – both are potentially detectable [1,2,3]. Our models differ from previous efforts [4,5,6,7,8] in that we incorporate freezing and quantify observable geochemical and geomorphic signatures such as discharge rate, total discharge volume, and W/R ratios.

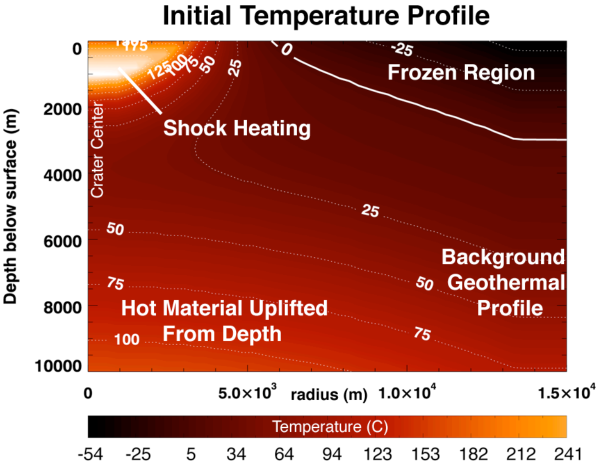

Figure 1: The energy delivered by a bolide and the redistribuiton of shock-heated material sets the stage for subsequent hydrothermal activity [*cf. 9,10,11*]. The initial temperature profile used in our simulations (shown here with the crater's floor at top and its center along the left boundary) exhibits four notable characteristics: a radially decaying shock-heated region, a subsurface field at radius that remains frozen, hot material that is brought from depth as the crater collapses from transient to final form, and a background geothermal profile of 40 mW m^{-2} that marks an ice-water interface at ~ 3 km depth.

Model Details: We simulate the evolution of PIH systems using MAGHNUM (*cf.* [12]). MAGHNUM solves the time-dependent transport of water and heat through a porous medium. It incorporates phase transitions between ice, water and vapor. We model PIH systems exposed to clement (5 °C) and subfreezing (-53 °C) atmospheres. Simulations run for 330 kyrs in a 2D axisymmetric domain that spans 30 km radially and 10 km deep (dr = 333 m, dz = 200 m). We assume surface permeabilities of 10^{-10}, 10^{-12}, 10^{-14}, and 10^{-16} m^2 that, along with porosity, decay exponentially with depth. The base of the domain is heated by a constant background geothermal flux of 32.5 or 40 mW m^{-2}.

Given a particular crater size and associated heat sources, two principal dichotmies control PIH behavior: (1) frozen vs unfrozen surface and (2) conductive vs convective heat and fluid transfer. The Rayleigh number (*Ra*), a nondimensional quantity, characterizes the vigor of convection:

$$Ra = \frac{\rho g \langle k \rangle \alpha q_{geo} H^2}{\mu \kappa K_T} \tag{1}$$

where parameters varied here include the domain averaged permeability $\langle k \rangle$, and the geothermal flux, q_{geo}. Other variables include: ρ, μ, and α, the density, viscosity and thermal expansivity of water, g, gravity, H, the domain height, and κ and K_T, the thermal diffusivity and conductivity.

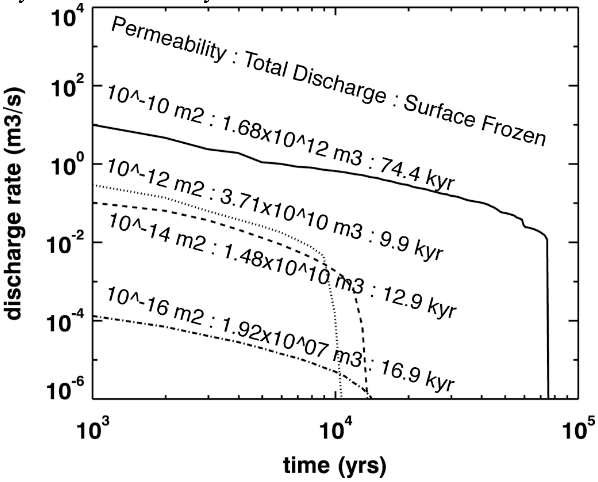

Figure 2: Discharge rate, total discharge, and system lifetime as a function of permeability for PIH systems exposed to a surface temperature of -53 °C. Convective systems (bold line) exhibit prolonged lifetimes and significant surface discharge. Conductive systems (thin lines) experience a trade-off between system lifetime and discharge rate but produce similar total discharges for modest permeabilities.

Results: W/R ratios increase with permeability. Higher permeabilities (10^{-10} m^2) allow convection. These systems yield much higher W/R ratios, longer system lifetimes (figure 2), and should produce spatially diagnostic mineral alteration patterns (figure 3). For conductive systems, the upper 200 m of rock at the crater's center experience fluid temperatures > 100 °C for 9000 yrs and W/R ratios of 10 when exposed to a surface temperature of 5° C. Subfreezing temperatures (-53° C) maintain upper 200 m temperatures > 100° C for only 600 yrs and W/R ratios are reduced to 1. Convective systems subjected to surface temperatures below freezing are particularly interesting because heat and fluid flow are forced towards the center of the crater. This prolongs high temperatures (>25° C for 25kyr) and yields W/R ratios > 1000. This may explain mineral assemblages and fluvial features associated with central peaks of craters [3].

References: [1] Moore J.M. and Howard A.D. (2005) *JGR* 110, E04005. [2] Schwenzer S.P. and Kring D.A. (2008) *LPSC* XXXIX, 1817. [3] Elhman B.L. et al. (2008) *Nat. Geosci.* 1, 355. [4] Newsom H. E. (1980) *Meteoritics,* 15: 339. [5] Newsom H. E. et al. (1996) *JGR*, 101: 14951-14956. [6] Rathbun J. A. and Squyres, S. W. (2002), *Icarus*, 157: 362-372. [7] Abramov O. and Kring, D.A. (2005), *JGR* 110, E9:12. [8] Barnhart C.J. et al., (2008) *LPSC* XXXIX, 2294. [9] Melosh, H.J. (1989), New York, *Oxford Univ. Press*. [10] Davies, G.F. and Arvidson, R.E. (1981) *Icarus*, 45: 339-346. [11] Shubert, G. and Solomon, S.C. (1992) Mars, *Univ. of Arizona Press*: 147-183. [12] Travis B.J. et al. (2003) *JGR*, 108, E4.

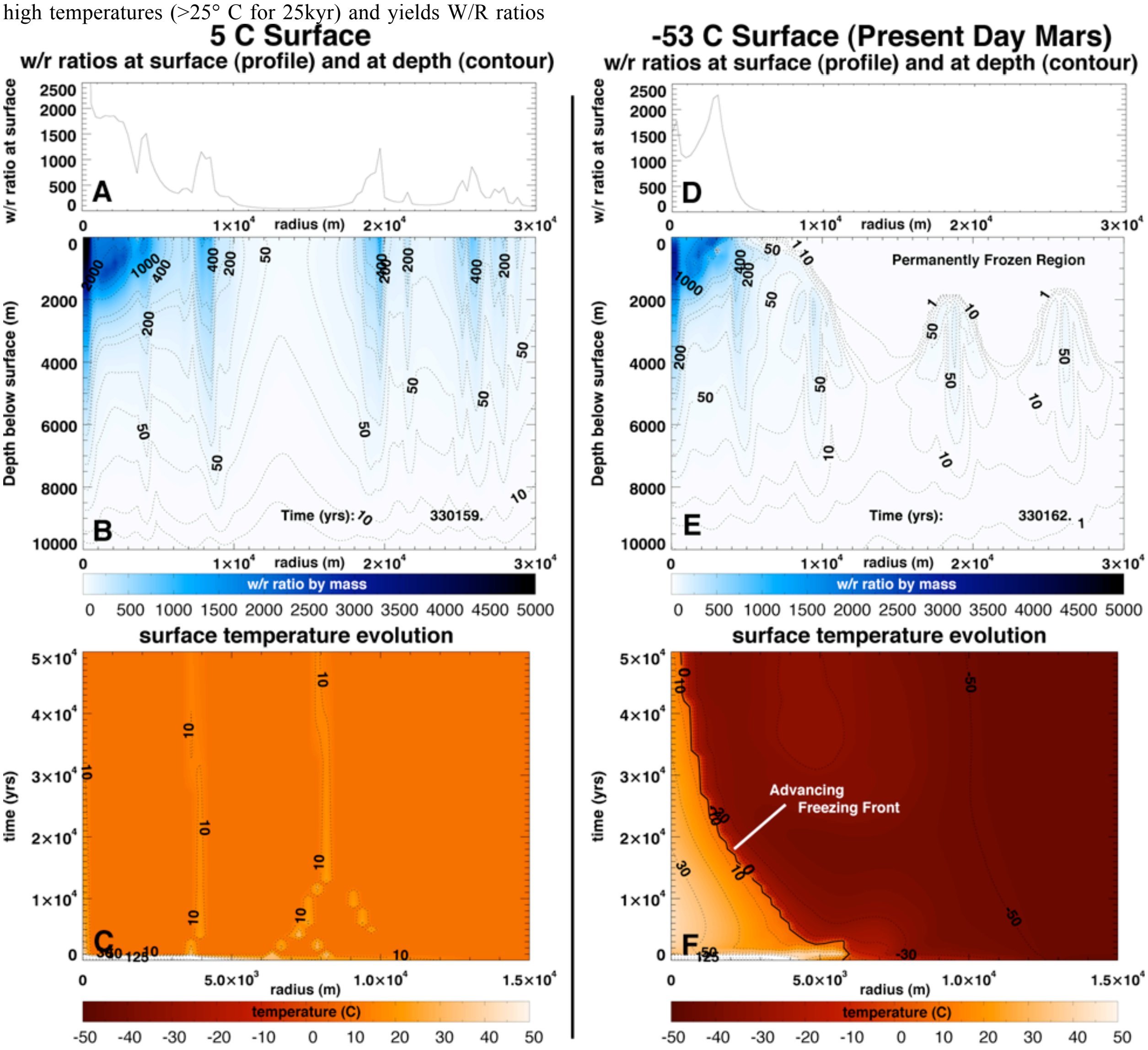

Figure 3: Final W/R ratios at the surface (panels A and D) and at depth (B and E) for two convecting ($\langle k \rangle$: 10^{-10} m^2, q_{geo}: 40 mW m^{-2}) PIH systems exposed to surface temperatures of 5 °C (left) and -53 °C (right). Panels C and F show surface temperature evolution. The frozen region is impermeable to flow and advances toward the center of the crater as the system cools. This concentrates flow and heat at the center of the crater. W/R ratio enhancment at the center of the crater and convective plumes would theoretically generate diagnostic patterns of mineral alteration.