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Impact ejecta-induced melting of surface ice deposits on Mars

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ABSTRACT

Fluvial features present around impact craters on Mars can offer insight into the ancient martian climate and its relationship to the impact cratering process. The widespread spatial and temporal distribution of surface ice on Mars suggests that the interaction between impact cratering and surface ice could have been a relatively frequent occurrence. We explore the thermal and melting effects on regional surface ice sheets in this case, where an impact event occurs in regional surface ice deposits overlying a regolith/bedrock target. We provide an estimate for the post-impact temperature of martian ejecta as a function of crater diameter, and conduct thermal modeling to assess the degree to which contact melting of hot ejecta superposed on surface ice deposits can produce meltwater and carve fluvial features. We also evaluate whether fluvial features could form as a result of basal melting of the ice deposits in response to the thermal insulation provided by the overlying impact ejecta. *Contact melting* is predicted to occur immediately following ejecta emplacement over the course of hundreds of years to tens of kyr. *Basal melting* initiates when the 273 K isotherm rises through the crust and reaches the base of the ice sheet ∼0.1 to ∼1 Myr following the impact. We assess the range of crater diameters predicted to produce contact and basal melting of surface ice sheets, as well as the melt fluxes, volumes, timescales, predicted locations of melting (relative to the crater), and the associated hydraulic and hydrologic consequences. We find that the heat flux and surface temperature conditions required to produce contact melting are met throughout martian history, whereas the heat flux and surface temperature conditions to produce basal melting are met only under currently understood ancient martian thermal conditions. For an impact into a regional ice sheet, the contact and basal melting mechanisms are predicted to generate melt volumes between $\sim 10^{-1}$ and 10^5 km^3, depending on crater diameter, ice thickness, surface temperature, and geothermal heat flux. Contact melting is predicted to produce fluvial features on the surface of ejecta and the interior crater walls, whereas basal melting is predicted to produce fluvial features only on the interior crater walls. Before basal melting initiates, the ice-cemented cryosphere underlying the crater ejecta is predicted to melt and drain downwards through the substratum, generating a source of water for chemical alteration and possibly subsurface clay formation. These candidate melting processes are predicted to occur under a wide range of parameters, and provides a basis for further morphologic investigation.

1. Introduction

The wide array of fluvial features present on the surface of Mars, despite its current below-freezing surface temperatures, has raised many questions regarding the climate of Mars throughout its early history. Fluvial channels incised onto impact crater walls, rims, and ejecta (e.g., Craddock and Maxwell, 1993; Craddock and Howard, 2002; Howard, 2007; Morgan and Head, 2009; Mangold, 2012; Mangold et al., 2012b; Hobbs et al., 2016) are particularly interesting because these features may offer insight into the conditions of the ancient martian climate, and its relationship to the impact cratering process. Fluvial channels have been reported around the rims and ejecta facies of impact craters spanning the entire martian geologic record. These include (1) Amazonian- and Hesperian-aged craters which exhibit fluvial channels superposing the crater walls and ejecta facies (Fig. 1A) (Morgan and Head, 2009; Howard and Moore, 2011; Jones et al., 2011; Mangold, 2012; Mangold et al., 2012a; Schon and Head, 2012; Hobbs et al., 2016). These channels are generally isolated with poor connectivity, and range from locally sinuous to wide and braided (Mangold et al., 2012a). (2) Relatively older early Amazonian- and Hesperian-aged closed-basin-lakes (CBLs) (Cabrol and Grin, 1999), which are craters that exhibit inlet channels superposed on the rim-crest (Fig. 1A). These inlet channels typically exhibit an amphitheater-shaped headwall

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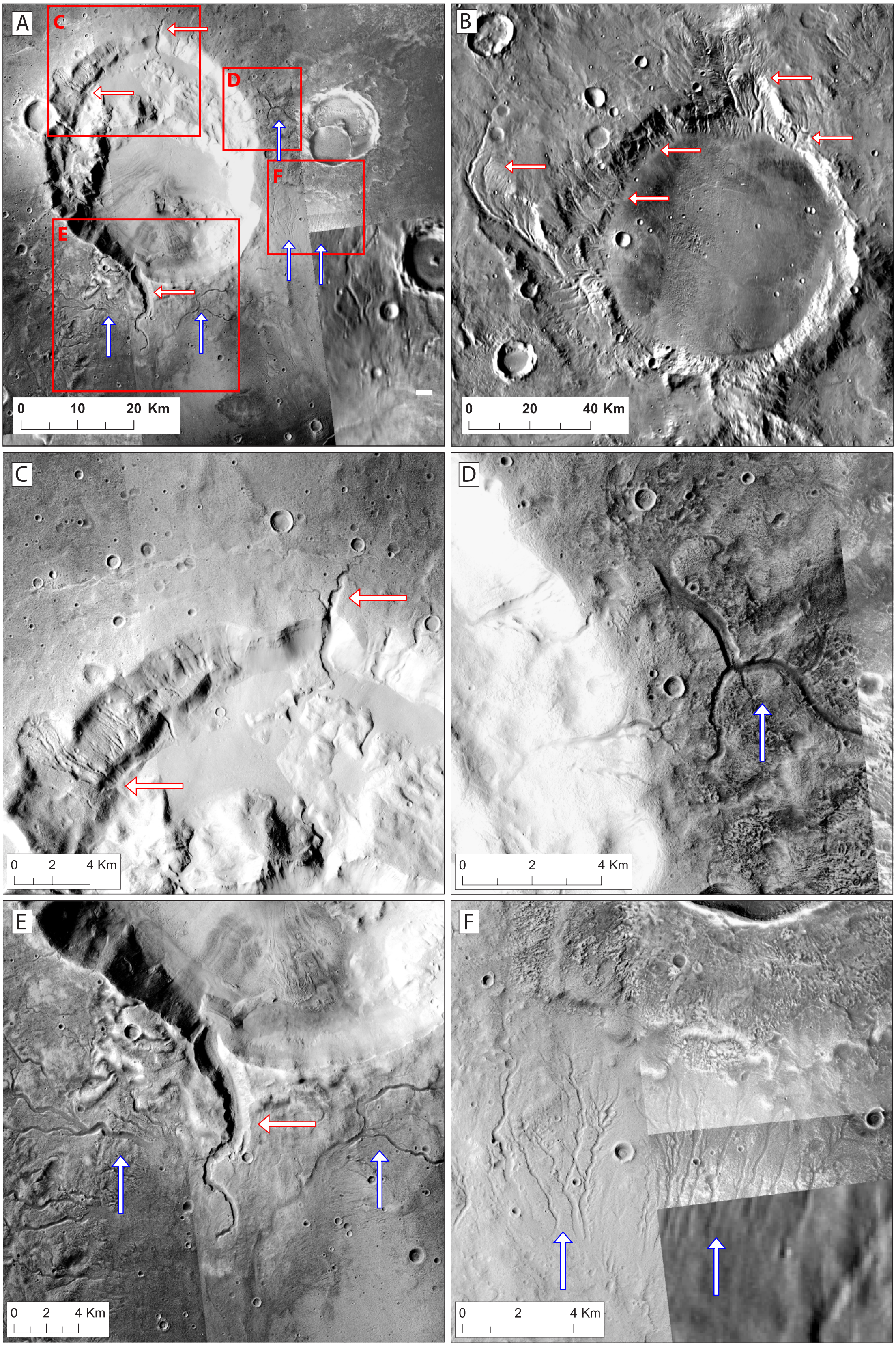

Fig. 1. Examples of fluvial channels associated with impact craters on Mars. (A) A 26 km diameter closed basin lake (CBL) exhibiting inlet channels on the rim (red and white arrows) and fluvial channels superposing the ejecta (blue and white arrows), and the ejecta of a younger nearby 12 km diameter crater characterized by Mangold (2012) (6.6 °E, 35.3 °N). (B) A highly degraded Noachian-aged crater exhibiting numerous fluvial channels along the rim characterized by Mangold et al. (2012b) (59.1 °E, 18.8 °S). (C–F) Fluvial features from (A). (A) CTX images B01_009892_2148, P21_009325_2160, D15_032968_2170, and D15_033047_2171 superposed on THEMIS IR global day. (B) THEMIS IR global day. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)