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Inverted Fluvial Channels in Terra Sabaea, Mars: Geomorphic Evidence for Proglacial Lakes and Widespread Highlands Glaciation in the Late Noachian

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Most Noachian-aged craters on Mars have distinctive morphologic characteristics that suggest they were modified by runoff from rainfall in a predominantly warm and wet early Mars climate. However, melting and runoff of frozen water ice (snowmelt) represents a plausible alternative for fluvial erosion in the Noachian. In recent work, we described a "closed-source drainage basin" (CSDB) crater in Terra Sabaea that contained inverted fluvial channel networks and lacustrine deposits. The crater is not breached by fluvial channels and lacks depositional morphologies such as fans or deltas, which sets it apart from previously described open- and closed-basin lakes on Mars that are hydrologically connected to their surroundings. The lack of hydrologic connectivity, along with additional evidence of remnant cold-based glacial morphologies within the crater, led us to hypothesize top-down melting of a cold-based crater wall glacier as the source of runoff and sediment for the fluvial and lacustrine deposits, which produced one or more proglacial lakes within the crater.

Here, we describe the results of a follow-on survey of the region within 500 km of the first CSDB crater. We searched for examples of features that could be interpreted as inverted fluvial channels regardless of their location. Of the 42 inverted channel networks we identified, 19 are located within unbreached craters; 17 are within breached craters with at least one inlet but no outlets; and 6 are located in the intercrater plains. The features are not randomly distributed; rather, they form two distinct groupings, one in the southwest of the study area and another in the east, with very few in the north or west. All but one occurs within an elevation range of 0 to +3 km. There are several previously identified closed-basin lakes within the study area, but none contained inverted channels.

The 42 inverted channel systems represent a wide variety of geologic and hydrologic settings. The region has distinctly low valley network density, and the few mapped valley networks in the region are clustered around +2 km elevation. If the fluvial regime were controlled primarily by elevation, and assuming no significant sequestration, lower elevations should have greater overall runoff production due to the accumulation of flow from upslope. The difference between breached and unbreached craters could therefore represent glacial melting occurring within craters (higher elevation) as opposed to significantly upslope of them (lower elevation), which would instead

promote runoff and breaching of craters by valley networks.

We previously described a single CSDB crater that showed evidence for cold-based crater wall glaciation, sedimentation and proglacial lake formation, but this new work adds a significant body of evidence that such processes were operating at much greater regional scales. While runoff from rainfall is usually considered the most likely mechanism of fluvial erosion in the Noachian, the possibility remains that fluvial erosion could have occurred via snowmelt in a subfreezing ambient climate. We have provided compelling evidence that fluvial and lacustrine features could have formed in such a climate and that Noachian Mars may have been colder than previously believed.