INTRODUCTION AND BACKGROUND: It has long been known that Mars contains polar caps and that they are comprised largely of water ice and dust [e.g., 1]. Less well-understood is the presence and nature of glacial flow in polar regions [e.g., 1], the possibility of glacial processes operating outside the polar regions [e.g., 2], and the mode of formation of circumpolar craters that contain significant high albedo mounds and deposits [e.g., 3]. Recent studies have shown that debris-covered glacier-like deposits occur in mid-latitude impact craters [e.g., 4, 5] and that circumpolar craters (65°-80° latitude) currently contain remnant ice deposits some of which may be glacial in origin [e.g., 3]. Analysis of new Mars data and a better understanding of glacial processes in terrestrial hyperarid, cold polar deserts analogous to the Mars environment, have documented the presence of tropical mountain glaciers and their distinctive deposits [e.g., 6-7]. These latter studies have shown that many glacial deposits on Mars represent the process of cold-based glaciation [6], which produces a distinctive set of features known as drop moraines. These features, well displayed in the Antarctic Dry Valleys [6,8,11], form when sublimation from the glacial front and ice forward velocity are in equilibrium so that there is no net movement of the front. In this case ice and contained debris move forward to the margins of the glacier, the ice sublimes, and the debris falls out of the ice and drops to the front, forming accumulations known as ‘drop moraines.’ Periods of increasing sublimation or decreasing velocity can result in ice front retreat; a new drop moraine will form when equilibrium is again reached. In this manner, a series of drop moraines can form parallel concentric ridges marking the successive stands of the cold-based glacier margin. Dozens of such parallel ridges form drop moraines on the Arsia Mons tropical mountain glacier [6-7].

Most circumpolar craters that show evidence of icy fill have distinctive concentrations of ice around the central peak (e.g., Korelev), lobate deposits attached to polar layered terrain, or isolated mounds of material usually along the base of the pole-facing crater wall [e.g., 3, 9]. Here we report on a crater in the same 65°-80° latitude range, but with a distinctly different ice-related crater interior deposit. We describe the crater occurrence and characteristics, its distinctive deposits that we interpret to be remnant moraines, and the conditions and sequence of events implied in its origin and evolution. We conclude that this feature represents a cold-based glacier that formed as a result of snow and ice accumulation on the eastern rim of the crater due to localized environmental conditions, and that the cold-based glacier flowed down the crater wall, climbed the central mound and was passively diverted by them, and underwent several phases of advance and retreat. These deposits appear to be very young in age.

DESCRIPTION: The 26.8 km diameter crater at 70.32°N, 266.45°E (Fig. 1) is about 1.6 km deep and was formed in the Vastitas Borealis Formation. It is characterized by a somewhat degraded lobate ejecta deposit, a distinctive central peak rising about 500 m from the crater floor, and a flat floor (Fig. 1a). Topographic and slope profiles (Fig. 1b-c) show that the SE portion of the floor is shallower and lies about 250 m above the NW floor; crater walls are steeper on the SE than the NW. THEMIS data reveal the presence of a complex set of ridges, tens to several hundred meters across, extending from near the SE crater rim crest, down the crater wall and out onto the crater floor (Fig. 2, 3). Along the crater wall the ridges are oriented generally radially to the crater, begin to become arcuate on the crater floor, and then display multiple, tight lobate patterns in the vicinity of the central peak (Fig. 3). Some ridges, particularly the marginal ones, are very continuous and extend as much as ~15 km from the crater wall down onto the crater floor. The pattern of ridges forms a pincher-like structure on and around the central peak (Fig. 3). Perspective views (Fig. 2) show that the set of ridges forms a contiguous deposit extending down the wall and out onto the floor, rising up onto the central peak summit and then bifurcating and forming two marginal

Fig. 1. A) MOLA gridded altimetry data superposed on THEMIS image V05259017; B. Topographic profile along A-A’ (Fig. 1a); C. Slope along same profile.
lobes. The southern lobe extends ~2 km further than the northern one, actually rising up onto the base of the western crater wall. All concentric ridge structures are convex outward, away from the SE wall. Associated features include a few dark patches, interpreted to be eolian deposits superposed on the lobate deposit; no evidence of additional structures such as fractures or channels, were observed. Superposition relationships show that the deposit largely overlies radial wall textures and deposits at the base of the walls (Fig. 2, 3). The internal stratigraphy of the deposit shows that the ridges form several sets of broad, continuous lobes of different sizes that are superposed on one another, often with no disruption of the underlying ridges, but in many cases apparently obscuring them due to deposition (Fig. 3). The superposition relationships imply several phases (at least 4) of successive lobe formation. In some cases, narrow concentric ridges are seen forming tight fold-like features (SW lobe of the pincher).

**Interpretation and Conclusions:** The ridges and the deposits are unlike structural wrinkle ridges, inverted streams, eskers, exhumed dikes, landslide scarps, crater ejecta, or typical mass movements. They are most similar to ridges associated with cold-based glaciers on Earth [8,11] and Mars [4-7]. On the basis of the size and morphology of the ridges, their convex outward shape, their clear control by the topography of the wall and central peak, their discrete patterns, and their multiple superposition relationships, we interpret the ridges to be moraines associated with phases of advance of glacier lobes from the southeastern margins of the crater wall and rim. In this interpretation, snow and ice accumulated on the SE rim and wall, incorporated debris from the crater wall, and flowed down the wall and out onto the crater floor, riding up on the central peaks, and then bifurcating and extending out onto the NW crater floor. Changing climate conditions caused the retreat of the ice, leaving moraines and deposits of glacial till. Distinctive superposition relationships suggest that advance and retreat occurred several times, and sharp preservation of underlying moraines below later moraines suggests cold-based conditions [6-8, 10-11]. We are currently establishing the internal deposit sequence of events in detail and exploring the range of conditions that might favor the accumulation of snow and ice in this particular configuration, in order to explore links between these deposits and climate cycles.


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**Fig. 2.** Perspective views of crater interior (THEMIS V05259017 on MOLA altimetry). A. Looking NW. B. Looking SE.

**Fig. 3.** Crater interior wall and floor structure. A) Portion of THEMIS V05259017. B) Sketch map of the ridges and their relationships.