A similar depressed segment is found along the northwestern rim that extends for ~2.1 km (Fig. 3B, C). The base of the exterior crater wall at these locations is truncated in comparison to the wall below preserved portions of the rim (Fig. 3A).

On the surrounding plains at both of these locations, pronounced north-trending lobate ridges (continuous ridges with an arcuate planform) are observed emanating directly from the depressed portions of the crater rim (Fig. 3). For the northern example, a mantled but well-defined lobate ridge extends radially from the crater rim for ~2.5 km. The lobate ridge is ~750 m across at the base of the crater wall, and the ridges that delineate the lobate margin are 200 m across and are less well-defined at the lobe's distal margin. Heavily subdued concentric ridges are observed ~700 m outside of the well-defined lobe, and these ridges directly correspond to the margin of the depressed portion of the crater rim (Fig. 3B). For the northwestern depressed portion of the rim, another mantled but well-defined lobate ridge is observed extending to the north. This lobate ridge is ~1.1 km across at the crater wall, and the ridges that bound the lobe are ~250 m across and also are not as well-defined towards their distal margins. At the terminus of the lobate ridge, a more subdued lobate ridge is observed ~600 m downslope. This lobate ridge is concentric with the well-preserved lobate ridge.

The correlation between the lobate ridges on the plains and the depressed portions of the crater rim provides evidence that material entered the smaller crater from the south, filled the crater and overtopped the rim in these two location. The alternate hypothesis, that flow within the system has only been from north to south, does not account for these features. MOLA tracks were not obtained at either of the depressed portions of the crater rim, but nearby tracks provide an upper bound (maximum elevation) of the rim at these locations. For the northern depressed portion of the rim, nearby track 13024 (Fig. 2D) determined a rim elevation of −3190 m. For the northwestern example, track 11867 obtained data directly at the eastern margin of the depressed portion of the rim, and found a rim height of −3173 m. During the most recent phase of crater-filling, material reached this approximate elevation before overtopping the crater rim and flowing onto the exterior plains.

Using this evidence for crater filling and overtopping in the superposed crater, we analyzed in detail the margins of the exterior crater wall for the larger crater to look for evidence of overtopping and flow on the adjacent plains. On the northwestern rim of this crater (Fig. 2A,B), individual lobate ridges similar to those observed on the plains exterior to the superposed crater are observed to trend radially from the larger crater towards the northwest (Fig. 5). Based upon high-resolution data acquired by CTX, these lobate ridges also appear to emanate from depressed portions of the crater rim and extend for ~3 km. The lobate ridges are mantled, but still allow for approximate measurements: the most prominent lobate ridges are ~1.1 km across at the entire lobe at its widest, and the ridges themselves are ~300 m across. These are nearly identical in size and morphology to the lobate ridges observed on the outer margins of the superposed crater to the north. Concentric lobate ridges are not observed beyond the margins of the proximal lobate ridges though the terrain has been significantly mantled and subdued. Much of the exterior walls of the larger crater are characterized by the same lineated terrain that is observed along the interior crater wall and the scarp that marks the contact between the two craters (Fig. 4A). The eastern exterior wall, however, shows a broadly sinuous but locally lobate ridge that extends parallel to the crater rim for ~20 km (Fig. 6). The ridge itself is heavily pitted and dissected and protrudes through the stippled terrain that characterizes the surrounding plains to the east. This portion of the exterior rim is on the opposite side of the crater rim from the most well-developed lobate flows on the crater interior (Fig. 6). The exterior crater wall itself is heavily mantled by smooth material and does not show significant evidence for downslope movement of material, though several localized units of lineated terrain are observed emanating from broad valleys incised into the exterior crater wall. The crater rim itself is well-preserved, and it remains unclear whether the sinuous ridge on the exterior plains is (1) evidence for overtopping of the crater rim, (2) a deposit formed from localized mobilization of material on the exterior crater rim, or (3) remnant topography from proximal ejecta deposits that has been heavily mantled.

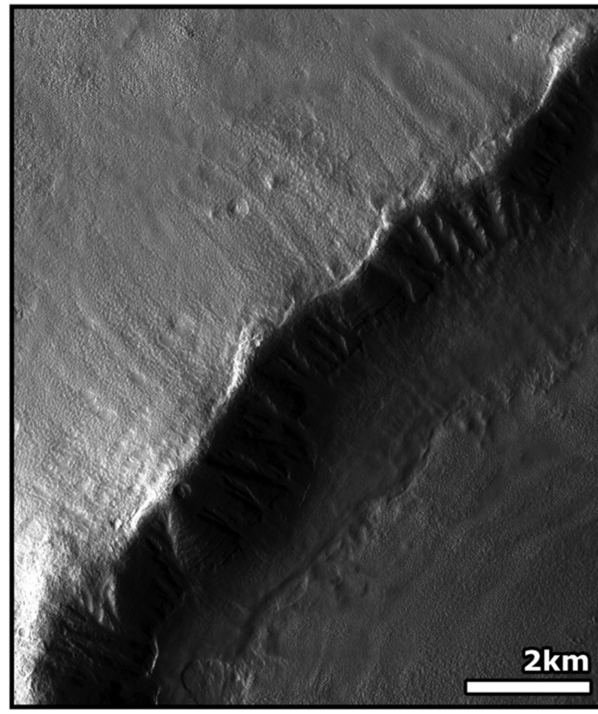

Fig. 5. Part of CTX image P01_001619_2232, showing ridges on the plains exterior to the larger, older crater (Context provided in Fig. 2A).

4. Interpretation

The large crater within this study area shows the classic surface morphology and topographic asymmetries of concentric crater fill (CCF) in the mid-latitudes of Mars, interpreted to form from ice-related processes (Squyres, 1979; Levy et al., 2009). The unique geometry of a perched crater on the northern rim and the interactions on the surface between these craters provides a window into the geologic history of this region that precedes the latest episode of CCF activity. Here, we use these observations and the stratigraphic relationships among the various units to propose a sequence of events that appears to require significant amounts of glacial ice to produce the observed landforms.

4.1. Initial formation of two-crater system

The initial impact event that formed the large underlying crater occurred at the contact between the Phlegra Montes to the east and the Vastitas Borealis Formation to the west (Fig. 1). Phlegra Montes is a region where mapping has shown local concentrations of LVF, LDA and CCF (Squyres, 1979), all of which are generally interpreted to arise from ice-related processes, either by ice-assisted creep of relatively dry material (Squyres, 1979; Lucchitta, 1981), or cold-based debris-covered glaciers in the Late Amazonian (e.g. Head et al., 2005, 2006a,b; Dickson et al., 2008; Holt et al., 2008; Head et al., 2010-this issue; Plaut et al., 2009). The Hesperian-aged Vastitas Borealis Formation (Greeley and Guest, 1987; Tanaka et al., 1992) covers the majority of the northern plains of Mars, and in this region HRSC data