Introduction: In this report, we re-examine the debate over the origin of the Martian polar chasmata based on new imaging data provided by the Thermal Emission Imaging System (THEMIS) [1], topographic data from the Mars Orbiter Laser Altimeter (MOLA), and high resolution images from the Mars Orbiter Camera (MOC) [2]. Our primary focus is the north polar region of Mars, including Chasma Boreale and two adjacent smaller chasmata (Figure 1). We conclude that a model for chasmata formation that emphasizes long-term aeolian erosion and modification of the polar layered material best explains the available data.

Figure 1: MOLA shaded relief context map of Chasma Boreale and the nearby smaller polar chasmata.

Observations: Figure 2 is a color THEMIS mosaic of the northern-most head scarp of Chasma Boreale. The geometry of the low-albedo sand dune field in this location is controlled by the orientation of the scarp. A majority of the barchan dunes have a single extended horn, suggesting a multi-directional wind regime [3]. Winds descending off the scarp from the E, NE, and N control the dune morphology. Figure 2 shows that the dune covered chasma floor is separated from the steep (15 - 25°) head scarp by a narrow moat located at its base. The low-albedo floor of the moat that lacks aeolian depositional features and exposes several small diameter (<5 km) impact craters. Downvalley from the moat, the chasma floor climbs in elevation and becomes dune covered. Collectively, these observations suggest that the base of the head scarp is a region of active aeolian scour. The low albedo floor materials are being eroded by the wind (to form a moat) resulting in accumulation of material a few km downchasma. The saw tooth pattern of dune deposition in the THEMIS mosaic suggests a variation in down scarp wind velocity. This variation in wind velocity and uneven scarp retreat, is also suggested by many smaller wavelength arcuate forms that collectively make up the main head scarp.

Figure 2: Color THEMIS VIS mosaic of Chasma Boreale’s head arcuate scarp.

Similar morphologic relationships exist at the southern-most arcuate scarp at the head of Chasma Boreale (Figure 1). Here, low albedo basal layered materials are removed from the base of the scarp and transported several km down chasma. A low albedo moderately cratered surface is visible at the immediate base of the southern scarp. These observations are consistent with the hypothesis of active aeolian undermining of the north polar arcuate scarps as initially suggested by [4,5].

The medial section of Chasma Boreale is dominated by low albedo barchan, seif, and transverse dunes and local bright dust mantles. The orientation of sand dunes in this region suggests a dominant wind direction from the NNE and NW, consistent with the flow of katabatic winds down chasma and off the steeper NW chasma wall.

The distal region of Chasma Boreale is characterized by isolated, low albedo dune forms and bright deposits interpreted to be dust mantles. The orientations of aeolian features in this region suggest three major wind source directions. The first source direction is to the NNE, and is derived from winds directed down chasma. The second source is located to the NW and is likely related to katabatic winds flowing down the steeper NW chasma wall. The third source is from the ESE. This dune orientation is likely controlled by winds flowing down the gentle SE wall. Sand dunes and dust mantles are notably absent at the base of the unusually steep scarp (~ 8 - 10°) of the distal section of the NW chasma wall. This region, centered at 80.56° N, 300.09° W, exhibits well-defined polygonal troughs. A localized erosive wind regime appears to explain the absence of depositional features and the sharply defined appearance of the polygonal troughs in this area.
The floors of the two smaller chasmata west of Chasma Boreale also contain isolated barchan dunes, seif dunes, transverse dunes, and dust mantles. The inferred wind directions suggest strong off-pole winds, oriented perpendicular to the unusually steep (8 – 10°) sinuous scarp located at the headreaches and along the northern margins of the two chasmata. MOLA topographic profiles across the sinuous scarp front reveal the presence of a depression or moat immediately at the base of the scarp. This depression is comparable to that seen at the base of the head scarps of Chasma Boreale and appears to be erosional, owing to the absence of dunes or other deposits. The sinuous scarp exposes an obvious thick (30 – 50 m) resistant unit (Figure 3). Platy-weathering forms can be seen on the slope of the scarp front, suggestive of active aeolian modification and erosion of the scarp by off-pole winds.

**Figure 3:** THEMIS image V13634005 of the sinuous scarp located near the head of the two small polar chasmas.

**Discussion and Conclusions:** Based on inferred wind directions and the geomorphology of the head scarp regions of Chasma Boreale and associated smaller chasmata, we propose a qualitative model for the long term evolution of the north polar chasmata. Off-pole katabatic winds have ablated polar cap materials and exposed layered materials along the margins of the polar cap. In some regions, differential erosion of specific layers in the PLD has resulted in the formation of scarps by headward retreat. The induration of polar layered materials is assumed to depend primarily on the relative abundances of dust and water ice.

The unusual steep slope of the sinuous scarp at the head of the two smaller chasmata, suggests an increased material resistance relative to other marginal areas of the polar cap. Along the sinuous scarp a resistant cap-forming unit is visible (Figure 3). Scarp retreat has occurred in places where the cap unit was undercut by descending slope winds. We suggest that an initial scarp aligned E-W along the cap margin has retreated with time in a general NE direction. The resultant retreat has generated the modern day sinuous scarp, the topographic depression at the base of the scarp and the two smaller chasmata. The large remnant of polar layered material located south of the head scarps of the smaller chasmata attests to the once broader extent of the cap in this region (Figure 1).

Examination of parallel trending polar troughs that occur along the NW wall of Chasma Boreale reveals that their equatorial slopes are also unusually steep, compared to other troughs across the cap. This suggests, similar to the sinuous scarp front, the presence of unusually resistant layered materials along the NW wall of Chasma Boreale. We therefore suggest that an initial scarp in the polar cap, aligned NE-SW, parallel to the modern day NW wall of Chasma Boreale, served to enhance off-pole katabatic winds. Aeolian erosion, concentrated at the base of this scarp, generated an initial NE-SW trending linear depression. This depression widened with time due to NW directed retreat of the scarp material. In addition, headward retreat occurred in a NE direction along the active northern head slopes of the initial depression. The modern day head scarps of Chasma Boreale are the current active sites of NE directed retreat. Given the total volume of material missing from Chasma Boreale (3.5 x 10^6 km^3) and a minimum chasma age of 10^6 years [6] (from crater counts of the polar cap surface) a maximum erosion rate of 0.35 km^3 yr^-1 was calculated. Removing this volume of material with time from both the NW wall and head scarps of the chasma gives a rate of PLD retreat of ~0.5 myr^-1.

An important observation along the sinuous scarp is the presence of two amphitheater forms located above the sinuous scarp cap-forming unit, ~ 20 km NE of main scarp rim (Figure 1). These two forms are developing within a younger section of polar layered materials. Similar to the sinuous scarp front, these features are capped by a thicker resistant layered unit. A topographic depression and scoured surface are also evident at the base of the scarp. We suggest that this second set of arcuate forms represent an early stage of scarp formation in the polar cap. The enhancement of katabatic wind velocities downslope from this feature could be expected to cause erosional deepening at its base and retreat of the rim. It is conceivable that over geologic time scales, such erosional dynamics could produce features comparable in size to Chasma Boreale.