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Scarp Retreat on MU69: Evidence and Implications for Composition and Structure

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Abstract

Crenulated scarps and other unit boundary patterns are consistent with scarp retreat. If indeed scarps have retreated on MU_{69} the most likely process is sublimation degradation. This explanation has implications for both original volatile composition and structure (layering) of MU_{69}.

1. Introduction

The flyby of the cold classical Kuiper Belt Object (KBO) 2014 MU_{69} (informally named Ultima Thule) by NASA's *New Horizons* spacecraft on January 1st 2019 revealed the surface geology of an object of this type for the first time [1]. Sublimation-modified landforms, as are commonly seen on comets and a number of other Solar System objects (including Pluto), could potentially have developed on MU_{69} even if it has never spent any time closer to the Sun than theory suggests for cold classical KBOs [2]. The volatiles most able to sublimate and form erosional landforms would be surface exposures of N_2 and CO. If exposed at the surface, CH_4 will also sublimate, though much more slowly than N_2 and CO. The loss of these volatiles, if present in sufficient quantities and concentrations and susceptible to exposure at the surface, might form distinctive and diagnostic scarps, pits and perhaps lags [see refs in 3]. Here we discuss evidence in *New Horizons* data that just such scarps may well occur on MU_{69}, and the implications of such landforms for the composition and structure of this body.

2. Observations

MU_{69} is a contact binary formed of two separate, touching lobes, and the highest resolution imaging of the object has a 33 m pixel scale and a phase angle of 32°. The smaller lobe, informally named Thule (all names used here are informal), shows a distinctive, darker toned surface material (*dm*) that has, in places, a boundary expressing outward-facing pointed and angular projections and rounded, inward-facing indentations (Fig. 1). Various lighter toned terrains border the dark material. These include the plateau material (unit *pm*), which is a flat-topped region that is bounded by a crenulated scarp, and which appears to be elevated relative to its surroundings in stereo anaglyph views. Running down the center of the principal mapped outcrop of dark material is a sinuous deposit of bright material (unit *bm*), which appears in stereo observations to occur within a V-shaped trough. The rest of the surface of Thule, including the probable, ~7 km diameter impact feature named Maryland, has been mapped as undifferentiated material (unit *um*). A few sub-km, circular patches of unit *um* are seen enclosed by the dark material. It cannot be determined in stereo views whether either of unit *dm* or *um* supersedes the other topographically. Crossing the undifferentiated material near the terminator between Maryland and Ultima are a series of sub-parallel troughs, which are reminiscent of structural troughs seen on other small objects in the solar system [e.g., 2, 3].

3. Hypothesis and Conclusions

We suggest that the boundaries of the darker toned surface material (*dm*) have, at least in places, undergone scarp retreat. A very simple form of sedimentation and erosion involves the addition (accrescence) or removal (decrescence) of material uniformly over a regional surface [I]. A common example of accrescence and decrescence on icy surfaces is volatile condensation (uniform precipitation of ice) and sublimation. For a planetary surface, uniform removal of material from a landscape (decrescence) makes outward-facing

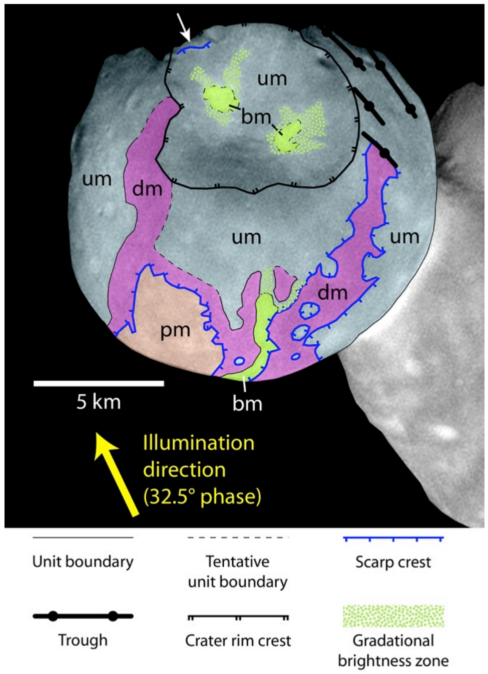

Figure 1. Geomorphological map of Thule. The base map used is a processed version of the CA06 LORRI observation (33 m pixel scale and 32° phase angle). *bm* = bright material; *dm* = dark material; *pm* = plateau material; *um* = undifferentiated material. Arrow: scarp well illuminated near terminator

projections increasingly pointed and angular while initial inward-facing indentations become rounded. During uniform accrescence, conversely, projections become rounded and inward-facing, and valleys remain or become sharply indented. These two processes are not reversible. The ground trace of the former edges of a plateau that has undergone scarp retreat through decrescence would not be matched if these same scarps later grew outward though accrescence. Martian south polar CO_2 scarps retreat by uniform decrescence forming "Swiss cheese" terrain [refs in 3].

If, in fact, scarp retreat has occurred on Thule, the dark tone of the material might be the consequence of a lag. This hypothetical lag could have formed from radiation-induced conversion of CH_4 into refractory hydrocarbons, and/or could be the collection of carbon-rich inclusions emerging from the originally volatile-rich deposit. In this scenario, the volatile loss armored the top of the deposit with a capping lag while the edges retreated, especially if the deposit's periphery rested on slopes. The location of the putatively retreated dark material near Maryland (Fig. 1) is consistent with impact related disruptions (extensional breaches) initially exposing near surface deposits of dark material to sunlight and making them susceptible to erosion. It may be the lack of such "large-scale" disruptions on Ultima (the larger lobe) that explains why surface materials with boundaries like those of *dm* are not seen there. If the dark material on Thule did form a discrete layer before being exposed to erosion, it might be taken as an indication that Thule is layered, as has been suggested for C-G and some other comets [refs in 2].

If this hypothesis is valid, then there are a number of candidate volatiles that could have sublimated to cause the lag formation and scarp retreat [1, 2]. CH_4 has already been mentioned and is thought to be an abundant constituent in a primordial CCKBO [2]. Also N_2 and CO are good candidates [2]. Additionally the presence of methanol, which as yet is the only material other than H_2O to have been detected by the spectrometer on *New Horizons*, could also have sublimated sufficiently at MU_{69}'s distance from the Sun to produce the hypothesized scarp retreat [1].

Acknowledgements

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