COLLISIONAL TERMINOLOGY FOR COLD CLASSICAL KBOs. N. R. Izenberg[1], P. K. Byrne[2], F. J. Calef III[3], D. A. Rothery[4], D. Pegg[4], C. Ahrens[5], [1]Johns Hopkins Univ. Applied Physics Laboratory, Laurel, MD, USA, [2]Planetary Research Group, Dept. of Marine, Earth, and Atmospheric Sciences, North Carolina State Univ., Raleigh, NC, USA [3]Jet Propulsion Laboratory, Pasadena, CA, USA, [4]School of Physical Sciences, The Open University, Milton Keynes, UK, [5]Arkansas Center for Space and Planetary Sciences, Univ. of Arkansas, AR, USA.

Introduction: The New Horizons [1] flyby of Kuiper Belt object 2014 MU_{69} revealed a primitive (i.e., relatively unprocessed) object that may be a remnant and representative of an early accretion phase of our solar system. Low-velocity, accretionary collisional evolution in the Edgeworth–Kuiper Belt has been described [*e.g.*, 2–4] and may be in evidence at MU_{69} by the "lumpy snowball" appearance of both lobes of the object itself. The initial medium-resolution image (140 m/px) obtained 12/31/2018 and released 1/1/2019 was taken at high solar phase angle, a poor illumination condition for determining topography. Nevertheless, immediate and rampant speculation on whether craters are present (and how many if so) occurred almost immediately.

Sub-hypervelocity impacts (averaging 0.38–0.46 km/s [3] at ~ 45 AU) of low-density icy bodies in the outer solar system probably result in accretion rather than disruption. The lumpy appearance of each lobe of MU_{69} may be the morphological expression of multiple deformational, but not destructive, low velocity "impacts". Such accretionary impacts of low-density materials are meaningfully different from more familiar impact processes that occur elsewhere in the solar system and require definitional distinction.

Blorping and Flomping: We argue that slow, accretionary impact processes on MU_{69} fall into two clearly definable and discrete categories.

1) Blorping (v.): A process wherein the sub-hypervelocity impact of two low-density bodies results in deformation of one or both bodies and accretion of the two into one larger body. The concomitant blorps (n.) are the accretionary morphological landform product of blorping, and may be the un-evolved progenitors of layerd "talps" seen on Comet 9P/Tempel 1 [5].

2) Flomping (v.): A process involving an *extremely* low-velocity "impact", possibly 1 km/hr or less (*e.g.,* equivalent to a cat falling sideways), of two bodies that results in little to no deformation regardless of body strength, but creates a possibly permanent contact binary.

At time of writing, it is unclear whether MU_{69} experienced any small-scale (i.e., sub-pixel in the 1/1/19 released image) hypervelocity impacts/micrometeorite gardening, etc. However, the observed morphology evident on the body suggests formation of each lobe by blorping. A preliminary assessment indicates that the smaller lobe shows around 4–7 blorps [Fig. 1] on the visible surface, and therefore possibly comprises an agglutination of 12–20 major pieces created via blorping. MU_{69}'s large lobe is about three times larger, has about 12 potentially distinguishable blorps on the visible side, and may have a volume of 30–50 smaller bodies blorped together. This inference assumes that blorping is not overly destructive of low-density body pore space and thus adds a significant volume rather than creating an albedo/texture feature that may make blorps look larger in volume than they are. Additionally, loss of pore space in KBOs that become inner solar system comets may be a key part of the process that converts blorps to talps [5].

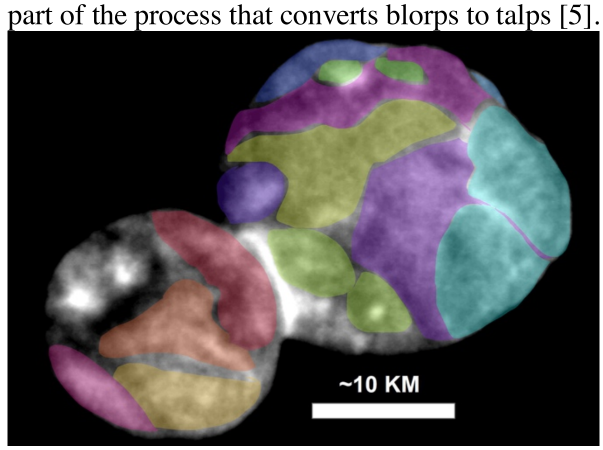

Figure 1. *Preliminary blorp map of MU_{69}. Colors distinguish potential discrete, possibly superimposed, blorp features.*

The final flomp of the two lobes together resulted in virtually no clear deformation of either body (*e.g.*, radial or circumferential lineations), and the high albedo 'neck' between the two was likely formed by a process(es) outside the scope of this work.

A more complex potential accretion history is consistent with some evolutionary models presented in early New Horizons MU_{69} public briefings (1/1/2019; Fig. 2). For example, one such scenario involves a combination of blorping and flomping within an early cloud of small icy bodies that leads to the accretion of each quasispherical lobe, with the smaller undeformed flomped lobelettes covered or later deformed by more energetic subsequent blorps. The local population of lobelettes clears over time either by accreting onto the two main lobes or by ejection from the accretion zone due the main lobes' gravitational influence. Finally, the two remaining lobes flomp together to make a snowperson.

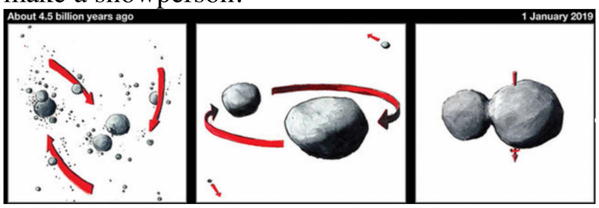

Figure 2. *Illustration of KBO accretion (NASA - JHUAPL-SwRI-James Tuttle Keane). Left: Blorping and flomping of small icy bodies. Middle: Two lobelettes dominate; Right: Final flomp.*

Blorp Smooshing and Flomp Sticking. The mechanisms involved with the "sticking" of icy aggregates can be approached using the aggregate's radius, mass density (known or predicted), Young's modulus (for a mixture dominated by water ice), and a range of surface energies [6]. Where prevalent, water ice dominates the collisional evolution, although other icy components (e.g., CH_4, CO_2, CO, NH_3) may also be at work [7]. The H_2O and CO_2 ice surface energies are in the range of 0.08–0.32 J/m^2 [6,8]. We calculate for that range the sticking velocity for a set of collisional icy bodies at various (estimated) distances (Fig. 3). The bodies we consider include Comet 67P (5.6 AU), Pan (9 AU), Kerberos (40 AU), and MU_{69} (46 AU). The CO_2 "frost line" in this solar system is at ~10 AU, so water ice is more dominant at Comet 67P and Pan, although CO_2 could still be a contributing (transient) factor farther out. As shown in Fig. 3, the greater the solar distance of an icy object, the more likely that object will have lower sticking velocity requirements and thus more likely to have undergone at least some assembly via blorping and/or flomping.

Indeed, sticking velocities can then be related to the likely amount of blorping experienced by a body. For example, although obviously neither is a classical KBO, we can regard Pan as representing an "extreme" case of blorping, and 67P, like Tempel 1, now considerably processed by repeated visits to the inner solar system and so comprising once-pristine blorps altered to talps. Conversely, it is possible that Kerberos, one of Pluto's smaller moons, can be considered a contact binary with a talp-like contact "neck", similar to Comet 67P, but having a much lower sticking velocity requirement. Finally, of the bodies we consider, MU_{69} has the lowest sticking velocity, thus reflecting an extremely low velocity contact 'impact' effect to acquire its present-day form, *i.e.,* flomping.

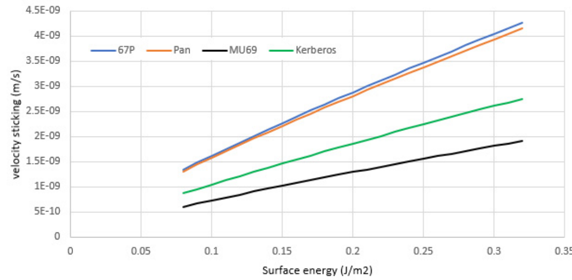

Figure 3. *Sticking velocities in solar system icy bodies.*

What About *Real* Impacts? An alternative (or complimentary) assessment of morphologies that resemble more classic high-velocity impacts is shown in Fig. 4. Lower phase angle observations will provide a clearer picture of the impact (or not) nature of these forms, thus strengthening or weakening our case for blorping of some or all of the visible surface of MU_{69}. Flomping of the two lobes, however, appears highly likely.

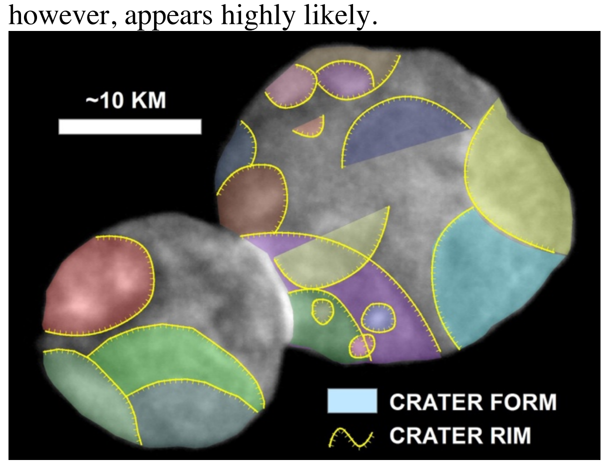

Figure 4. *Potential crater forms on MU_{69}. Crater forms and blorps are often, but not always, mutually exlusive.*

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References: [1] Stern *et al.,* (2018) *SSR*, 214(4); [2] Kenyon & Luu, (1998) *Astron J.* 115, 5; [3] Stern (1996), *Astron. J.* 112, 1203; [4] Davis & Farinella (1997) *Icarus* 125, 50-60; [5] Belton *et al.,* 2007 *Icarus* 187, 1;[6] Musiolik, G. *et al.* (2016) *Astroph. J.* 818, 1; [7] Leinhardt, Z. *et al.*, (2008) In: The Solar System Beyond Neptune, 195-211; [8] Wood, (1999) PhD thesis, Univ. California.