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LIKELIHOOD FOR RUBBLE-PILE NEAR-EARTH ASTEROIDS TO BE 1ST OR NTH GENERATION: FOCUS ON BENNU AND RYUGU. K. J. Walsh¹, R-L. Ballouz², W. F. Bottke¹, C. Avdellidou³, H. C. Connolly Jr.^{4,5,6}, M. Delbo³, D. N. DellaGiustina⁵, E. R. Jawin⁶, T. McCoy⁷, P. Michel³, T. Morota⁸, M. C. Nolan⁵, S. R. Schwartz⁹, S. Sugita⁶, D. S. Lauretta⁵, ¹Southwest Research Institute, Boulder, CO (kwalsh@boulder.swri.edu), ²Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, ³Laboratoire Lagrange, Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France ⁴Dept. of Geology, Rowan University, Glassboro, NJ, USA, ⁵Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, ⁶American Museum of Natural History, New York, NY, USA, ⁷Smithsonian Institution National Air and Space Museum, Washington, DC, ⁸Smithsonian Institution National Museum of Natural History, Washington, DC, USA, ⁹University of Tokyo, Tokyo, Japan, ¹⁰Planetary Science Institute, Tucson, AZ, USA

Introduction: Previous works have provided links between a few well-studied near-Earth asteroids (NEAs; specifically, Bennu and Ryugu), and potential source asteroid families in the inner Main Belt [1-3]. A challenging finding is that the surfaces of both NEAs have very young crater retention ages relative to the estimated ages of their source families [4,5,6]. Here we aim to determine the likelihood that they are direct products of a large asteroid family (1st generation), or are products from intermediate size remnants that have subsequently disrupted (2nd generation or, “Nth generation”).

Origins of near-Earth asteroids: NEAs are dynamically transient bodies that mostly originate in the Main Asteroid Belt [7]. In the Main Belt km-sized objects aren't expected to survive for timescales as long as the age of the solar system, but a way to refresh this population is through catastrophic collisions [8]. Asteroid families formed by the disruption of a ~100-km body could produce thousands of small, sub-km-sized rubble-piles [9]. Such events also produce a smaller number of intermediate-sized 1st generation rubble piles, 5- 10 km in diameter, that themselves are also subject to the collisional environment of the Main Belt and can later be disrupted to produce more, smaller, Nth generation rubble piles.

The probability of observing a 1st generation remnant from an asteroid family can be estimated by modeling an asteroid family created in a collision and following its members subsequent collisional evolution as its smallest members drift towards dynamical escape hatches by the size-dependent Yarkovsky effect. There is a competition between the very large number of first generation sub-km-sized members racing to reach an escape route before being destroyed in a collision and the 5- or 10-km rubble piles, moving more slowly, but more resistant to disruption and capable of producing a new generation of bodies if disrupted.

Modeling family formation and evolution: Here, we take advantage of some previously proposed linkages between known NEAs and their source asteroid families [1,2,3]. We built a Monte-Carlo-style model of the Eulalia and New Polana families, with generated starting population of members with a specific size

frequency distribution. These objects drift through the inner Main Belt with rates determined by their sizes and obliquity randomly assigned. If an object experiences a disruptive collision (tested probabilistically at each timestep) then a new family of smaller remnants is generated with its own size distribution. This new generation is also tracked and collisionally evolved.

Objects are removed when they cross the 3:1 resonance with Jupiter at 2.5 au, the v_6 resonance at 2.15 au. Sub-km objects have a 1/3 chance of removal when they cross the overlapping Jupiter 7:2 and Mars 5:9 resonances (at 2.255 au) [3].

Results: We find that for scenarios in the inner Main Belt the total number of escaping bodies is dominated by 1st generation rubble piles for the first ~1-2 collisional lifetimes of the target body of interest. For older families, with ages 2-3 times the collisional lifetime, the rubble piles reaching escape routes can be equal contributions of 1st and Nth generation objects, and beyond that they are dominated by Nth generation remnants.

Two possible families for both Bennu and Ryugu, Eulalia and New Polana, are old enough (~800 and 1400 Myr, respectively [3]) that Nth generation rubble piles are likely to be dominating the sub-km objects they are currently delivering to near-Earth orbits.

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