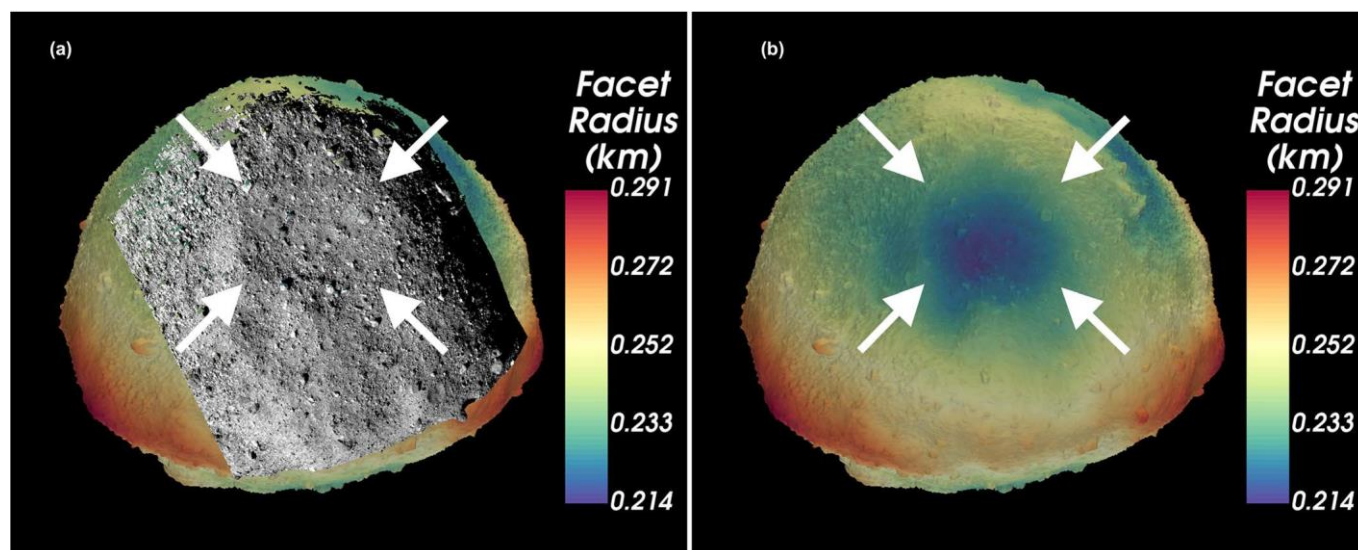
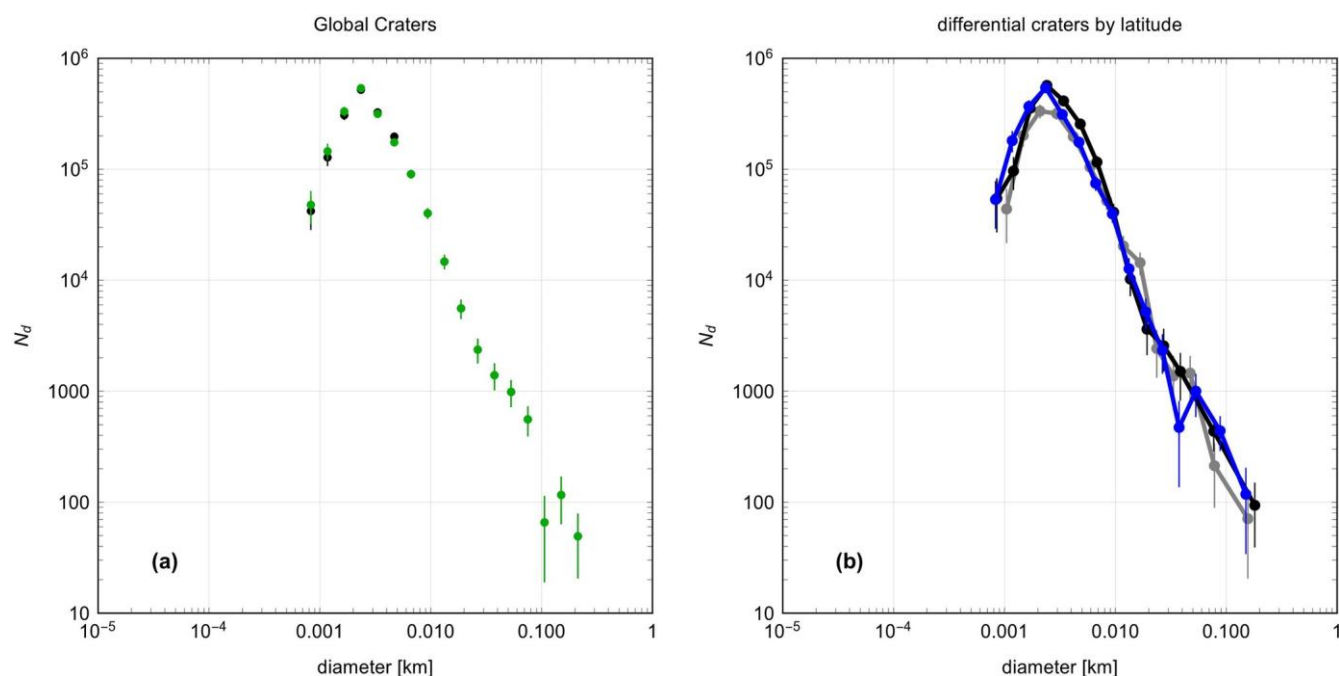
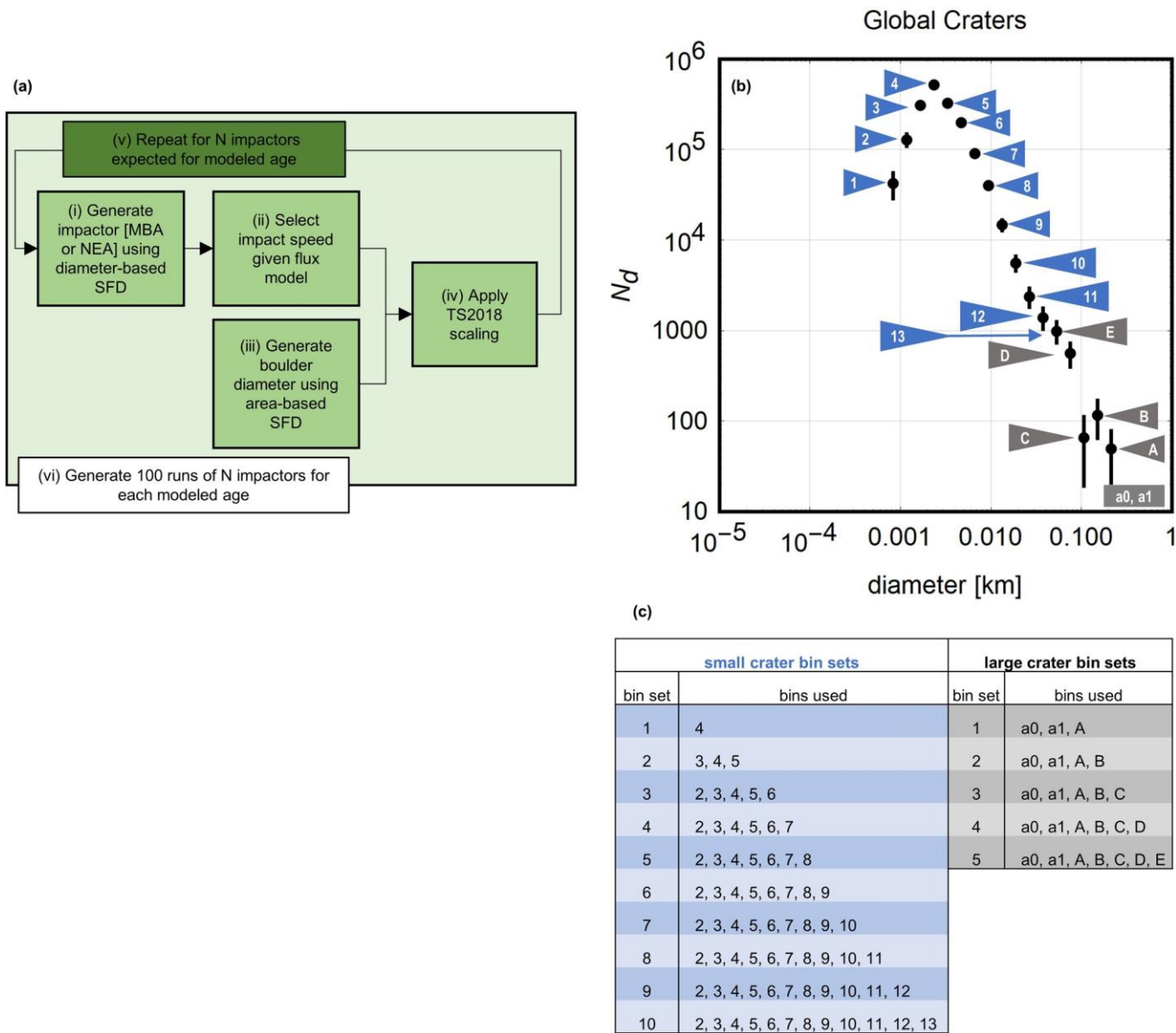




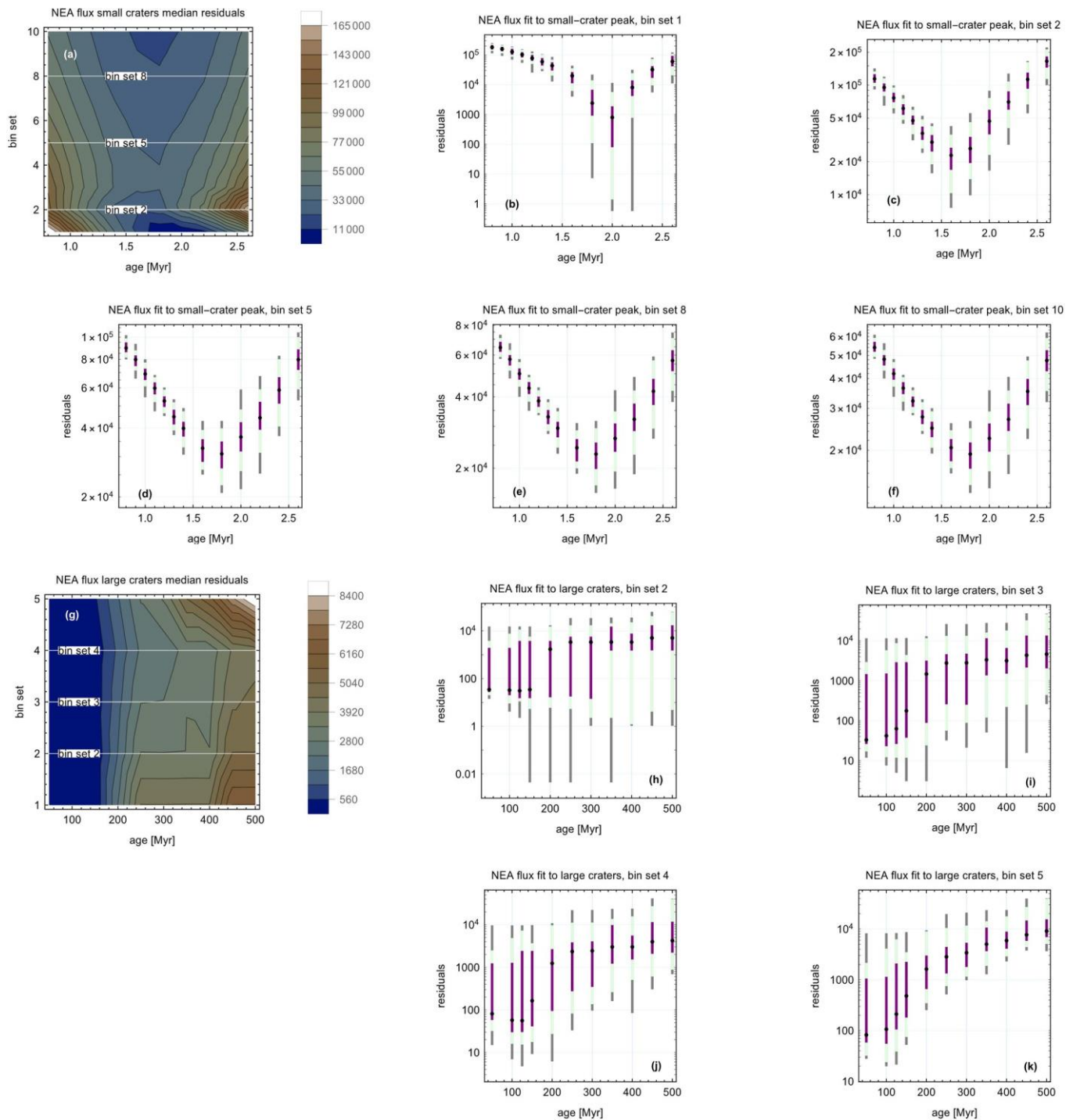
Extended Data Fig. 1 | Example identification of a large crater on Bennu. A 141-m-diameter crater on Bennu, centered at 55.7°N and 62.7°E. White arrows in both frames indicate the crater location. **a**, PolyCam image 20181202t050321s325_pol_iofl2pan projected onto the shape model. **b**, The shape model only, colored by facet radius. The images collected during the spacecraft's final approach (acquired in early December of 2018), in conjunction with the shape model, were used to identify and measure large craters on Bennu.



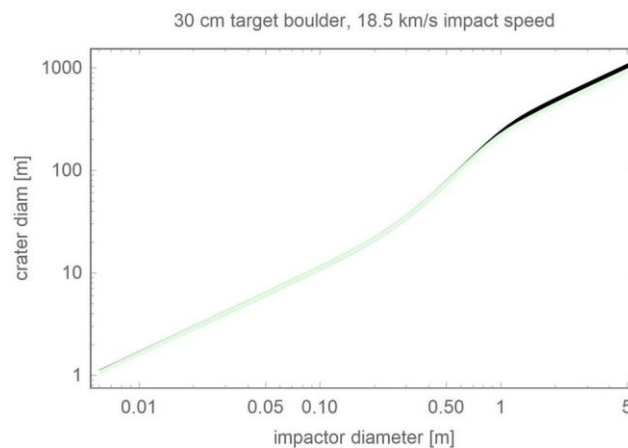
Extended Data Fig. 2 | Benu's crater abundance as a function of latitude and slope. **a**, The global SFD of Benu in differential format. The black data points are all craters, normalized by Benu's global surface area. The green points are a population that includes all craters within $\pm 60^\circ$ latitude, and craters > 5 m diameter for higher latitudes. The difference is a small vertical shift in the differential values for craters < 5 m, the nature of the fishhook shape is unchanged. **b**, The differential crater populations for three distinct slope/latitude regions (Scheeres et al. 2019) on Benu: the gray data are for craters $< -20^\circ$ S, the black data are for craters $> +20^\circ$ N, and the blue data are for craters within $\pm 20^\circ$ latitude. The fishhook shape is present in all three.



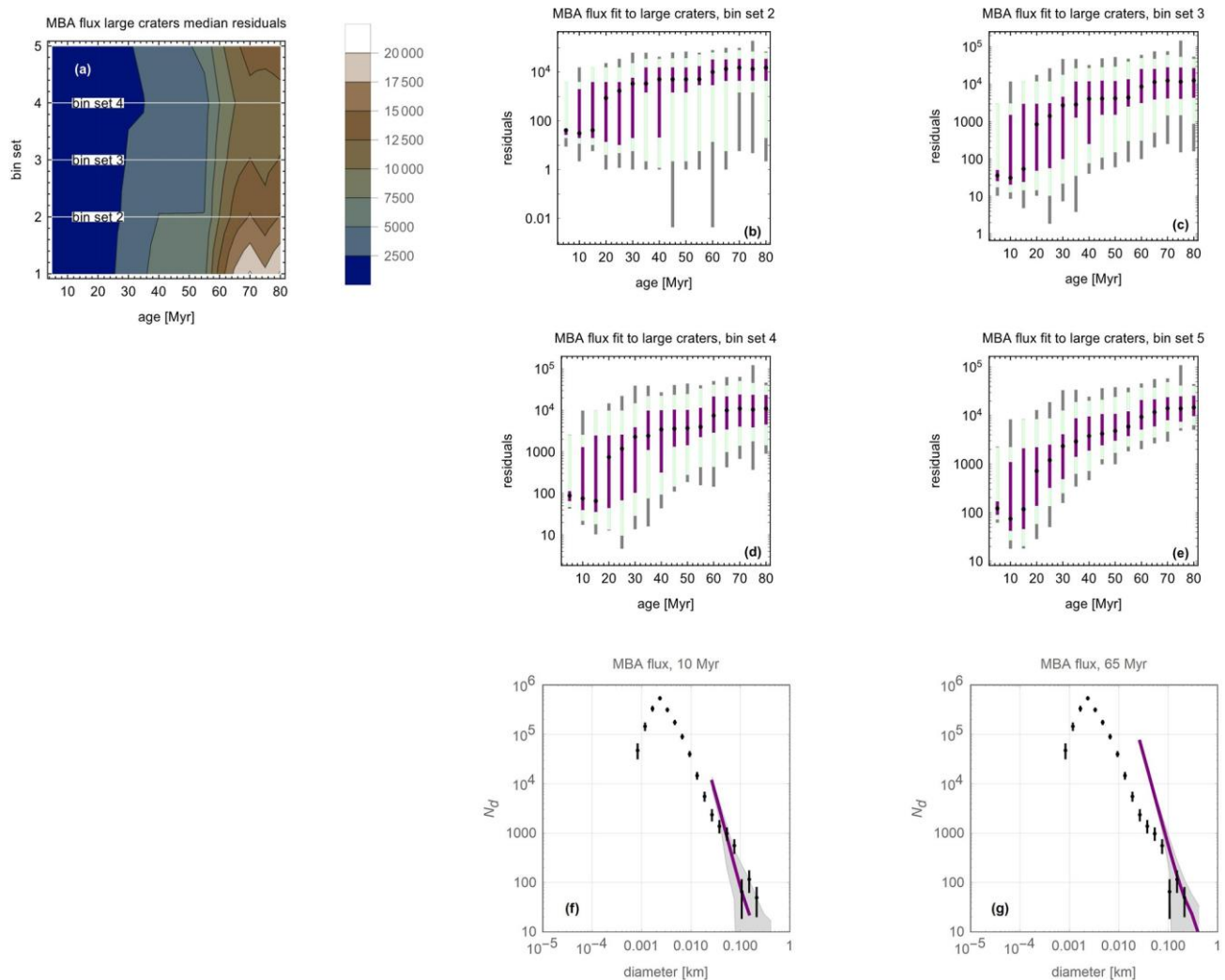
Extended Data Fig. 3 | A flow chart of our process for generating simulated crater populations for a given modeled age, and definition of the diameter bins used to calculate fits between the observed and modeled crater populations. **a**, A flow chart of our process for generating simulated crater populations for a given modeled age: (i) generate an impactor by sampling a diameter-based power-law SFD for either an MBA or NEA flux model; (ii) assign that impactor an impact speed based on the flux model; (iii) generate a boulder by sampling an area-based power-law SFD; (iv) apply TS2018 scaling for that combination of impactor and boulder; (v) repeat steps (i)–(iv) for N impactors predicted for the model age; (vi) repeat the generation of N impactors 100 times to sample the variability at a given age. **b, c**, Definition of the diameter bins used to calculate fits between the observed and modeled crater populations. The plot (b) labels small diameter bins with a number and large diameter bins with a letter. The table (c) lists the diameter bins used to define the bin sets used to compare observations with the model. For example, the small-crater bin set 5 uses diameter bins 2–8, and the large-crater bin set 4 uses diameter bins A–D. The labels a0 and a1 refer to the largest bin diameters that can occur in the older ages within the simulation data, which are larger than any of the observed craters on Bennu.



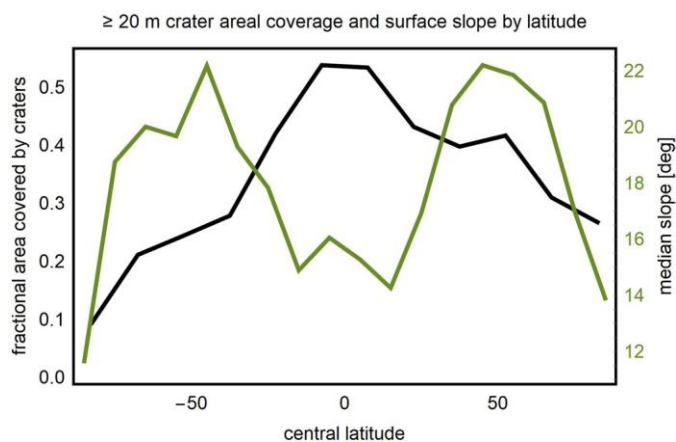
Extended Data Fig. 4 | Comparison between observed and modeled crater populations for Bennu's craters and an NEA flux. **a**, residuals for all combinations of bin sets and modeled ages for small craters. The residuals are in the same form as the differential SFD, which is $N/(dD A)$, where N is the number of craters in diameter range dD , and A is the surface area used for normalization, so are in units of $\#/(km^2)$. There is a consistent minimum across all bin sets. **b**, the specific residuals for bin set 1, which consists of diameter bin 4 (Extended Data Fig. 4). The black point is the median residual for the 100 runs, the purple line spans the 25–75% range, the light-green line spans the 5–95% range, and the gray line spans the 1–99% range. **c**, **d**, **e**, and **f** are the same as **b** for bin sets 2, 5, 8, and 10, respectively. We use the 1–99% minimum residuals across the modeled ages to bound the possible ranges for the small-crater retention age. Bin set 1 establishes the maximum age at 2.2 Myr; bin set 2 establishes the minimum age at 1.6 Myr. **g**, residuals for all combinations of bin sets and NEA modeled ages for large craters. **h**, the specific residuals for bin set 2, which consists of diameter bins $a0$, $a1$, A and B (Extended Data Fig. 4). **i**, **j**, and **k** are the same as **h** for bin sets 3, 4, and 5, respectively. We use the 1–99% minimum residuals across the modeled ages to bound the possible ranges for the small-crater retention age.



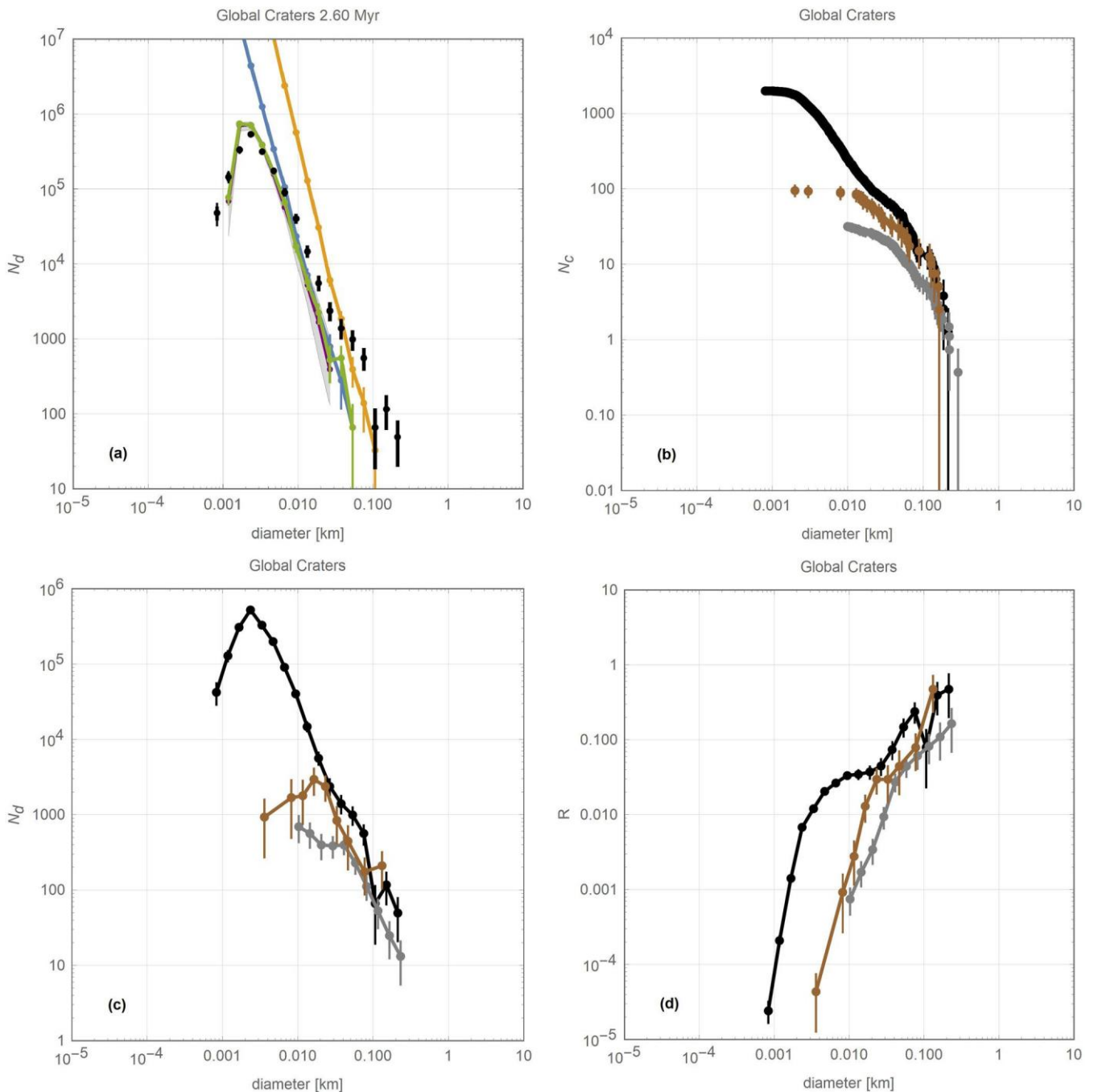
Extended Data Fig. 5 | Crater diameter as a function of impactor diameter for a 30 cm diameter target boulder and 18.5 km/s impact speed. Unlike strength and gravity scaling, which would be linear in this log-log plot, the TS2018 scaling transitions from an armoring regime at small sizes to a gravity regime at large sizes. There are two curves in the plot, one for the two gravitational end members present on Bennu (pole, light green, and equator, black), the resulting crater diameter is the same until ~200 m diameter. There's only one candidate impact feature on Bennu larger than this size, and because we calculate our ages against the binned differential data, the small difference in size for this one crater would not change its host bin. Thus, the variation in surface acceleration on Bennu does not change the outcome of our simulations.



Extended Data Fig. 6 | Comparison between observed and modeled crater populations for the large craters and an MBA flux. **a**, residuals for all combinations of bin sets and modeled ages. The residuals are in the same form as the differential SFD, as described in Extended Data Fig. 5. **b**, the specific residuals for bin set 2, which consists of diameter bins a0, a1, A and B (Extended Data Fig. 4). Colors are as in Extended Data Fig. 5. **c**, **d**, and **e** are the same as **b** for bin sets 3, 4, and 5, respectively. We use the 1-99% minimum residuals across the modeled ages to bound the possible ranges for the small-crater retention age. The broad minimum in bin set 2 establishes the maximum age at 65 Myr; the two smallest residuals at 45 Myr and 60 Myr correspond to two cases, one for each of those ages, when there were no modeled craters larger than the observed craters, and the number of modeled craters in bin A match the observations. Bin set 5 establishes the minimum age at 10 Myr. **f** and **g** are the differential versions of the observed crater SFD and TS2018 model fits (see also Fig. 1 and Fig. 4) for the 10 Myr and 65 Myr (minimum and maximum ages, respectively) with the 99% minimum residuals between observations and model results. The black data are the measured differential crater SFD of Bennu, the purple data are the median results of 100 runs, and the gray band is the 99% range of the 100 runs. Across this age span the range of the 100 modeled outcomes encompasses the variability in density seen in the three largest diameter bins.



Extended Data Fig. 7 | Large craters and surface slope on Bennu. A comparison between the fractional area covered by craters ≥ 20 m diameter (black line, left-hand axis) and the median surface slope (green line, right-hand axis) as a function of latitude. Unlike the small craters, which are not correlated with slope and latitude (Extended Data Figure 2), the abundance of larger craters is correlated with latitude and slope.



Extended Data Fig. 8 | Modeled craters for a 2.6 Myr NEA age, and comparison with Ryugu and Itokawa craters. **a**, This plot layers additional data sets over the style of presentation in Fig. 4. As in that figure, the black data are the measured differential crater SFD of Benu, the purple data are the median results of 100 runs for a 2.6 Myr NEA flux model, the gray band represents the 99% range of the simulation results. Here we also include the results of one run, showing a specific case of the TS2018 scaling (green data), 100 Pa strength scaling (blue data), and gravity scaling (orange data); these data illustrate the different resulting crater populations for the three scaling laws given the same impactors. Unlike TS2018 scaling, strength- and gravity scaling continue to produce smaller craters given smaller impactors. However, above the fishhook diameter range, the strength data fall in the range of the TS2018 results, indicating that cratering strengths ≤ 100 Pa give comparable results to TS2018 for diameters larger than the armoring regime. TS2018 scaling approaches gravity scaling at the largest diameters on Benu. Given that Benu has been dynamically decoupled from the main belt for 2.6 Myr, TS2018 indicates that all craters 5 m diameter could have been formed by NEA impactors. **b**, **c**, and **d** are a comparison between Benu's crater population (black) with Ryugu (gray) and Itokawa (brown) in cumulative, differential, and R-format, respectively.

Extended Data Table 1 | OSIRIS-REx mission data used for analysis

mission phase	dates of data used	data set	representative spatial sampling ¹	Typical phase angle	measured regions
Approach	December 1-2, 2018	PolyCam images	0.35 m/pix	~34°	Nearly global, with lower detection efficiency at high latitudes
Orbital A	January-February, 2019	MapCam images	0.11 m/pix	~95°	beyond 60 deg latitude
Detailed Survey	March 21-29, 2019	PolyCam images	0.05 m/pix	~41°	between +/- 60 deg latitude
Orbital B	June-August, 2019	OLA DTM	0.01 m	n/a	beyond 60 deg latitude
¹ spatial sampling refers to pixel scale for the images and post spacing for the lidar-derived DTMs					

Data from the mission phases used to identify, measure, and characterize Bennu's impact crater population.

Extended Data Table 2 | Symbols, units, and values used for the analysis in this paper

symbol	Value	Unit	Description
Impactor properties			
δ	2000	kg/m ³	bulk density
a	0.0025-5.0	m	radius
D_p	0.005-10.0	m	diameter
m_p	various	kg	projectile (impactor) mass
U	5.3, 18.4	km/s	mean impactor speed, MBA and NEA values ⁵²
θ	45	deg	assumed impact angle
Target properties			
ρ	1190	kg/m ³	Bennu bulk density
ρ_r	2000	kg/m ³	boulder density
Y	100	Pa	bulk target strength
m_r	various	kg	mass of target boulder on surface
g	5.42×10^{-5}	m/s ²	surface acceleration, a combination of surface gravity and rotation ²⁷
A_v	0.1886	km ²	Bennu's cross-sectional area
D_r	0.01-50.0	m	diameter of surface boulder
Housen and Holsapple crater scaling-relationships parameters			
μ	0.41	-	empirical constant, value for sand ⁵³
ν	0.4	-	empirical constant, multiple materials ⁵³
H_1	0.59	-	empirical constant, value for sand ⁵³
H_2	0.81	-	empirical constant, value for sand/perlite mixture ⁵³
D	various	m	final crater diameter (calculations done in m, plots in m or km)
R	various	m	transient crater radius
Tatsumi and Sugita (2018) crater scaling-relationship parameters			
Q^*_D	Various	J/kg	$(3.45 \times 10^2) \left(\frac{D_t}{2}\right)^{-0.47} + (2.72 \times 10^{-1}) \left(\frac{D_t}{2}\right)^{0.99}$, boulder disruption specific energy ¹⁹
Π			$\frac{m_p}{m_p + m_i}$
a^*	various		$\Pi^{-1/3} a$
K_1	0.24	-	empirical constant
K_2	0.01	-	empirical constant
μ_1	0.41	-	empirical constant
μ_2	1.23	-	empirical constant
π_2^*	various	-	$\frac{a^* g}{(U \cos \theta)^2}$, the $\cos \theta$ term means we apply only the vertical component of U
π_4	1	-	$\frac{\rho_b}{\delta}$
V_c	various	m ³	crater volume
U^*	Various	-	$\frac{(1 + \epsilon)}{1 + m_r/m_p} U$
ϵ	0	-	Coefficient of restitution (a 0 value is for an inelastic collision, relevant for impacts ¹⁷)
Main belt flux parameters			
P_i	3.29×10^{-18}	km ⁻² yr ⁻¹	
$a_{0,MB}$	2.7	-	exponent for the cumulative impactor power-law, extrapolated from ref. ³⁸
k	2.89×10^{-14}	-	coefficient for the cumulative impactor power-law, extrapolated from ref. ³⁸
Near-Earth flux parameters			
c_0	1.568	-	constant for the power-law SFD ⁴⁴
a_0	2.7	-	constant for the power-law SFD ⁴⁴
R_E	6378	km	Average radius of Earth

Symbols, units, and values used for the analysis in this paper.