A Comparative Study of Bennu, B-Type Asteroids, and Itokawa with Implications for the OSIRIS-REx Mission

Shailyn Altepeter(1), Zoe Marzouk(1), Ashley Morrison(1), Wenxian Zhou(1), Estefania Larsen(1), Ryan Clegg-Watkins(2)

(1) Millard South High School, Omaha, NE, (2) Washington University in St. Louis, St. Louis, MO

ABSTRACT

The success of the OSIRIS-REx mission depends on understanding the surface properties and mechanics of Bennu. Our objective is to compare Bennu (asteroid 101955) to other B-type asteroids (e.g., 59 Elpis, 2 Pallas, and 24 Themis) and to a small-sized asteroid close to Bennu's expected size, 25143 Itokawa. We report on properties such as albedo, orbit, density, and rotation rate of the four asteroids and compare these properties with data previously gathered for Bennu. We tie these findings back to the OSIRIS-REx mission objectives to provide mission scientists with information on the expected properties of Bennu and with information important to making the mission successful. We conclude that 59 Elpis is the most similar to Bennu. We suggest mission scientists look into these similarities to further improve their understanding of Bennu, as it will likely have many comparable physical properties as those seen on Elpis. Mission scientists can also extract valuable information from similarities and differences from the other asteroids studied here, especially to evaluate composition and geographic features on Bennu that are indistinguishable from telescopes on Earth.

INTRODUCTION

Bennu (101955) is a carbon-rich B-type asteroid that contains amino acids and organic molecules which might have been precursors to life.[1] Studying Bennu is imperative because it is a potentially hazardous asteroid that could strike Earth. Most studies have used radio and visible telescopic data to gather information about Bennu.[2] However, Bennu is a very small asteroid (mean diameter of 492+/- 20m)[1] and has proved challenging to study from the ground. The OSIRIS-REx mission will launch in September of 2016 and one of its mission goals is to obtain samples from Bennu's surface for future analysis.[4] Information from these samples is essential for enabling scientists to develop impact mitigation strategies and for understanding possible origins of life.

Bennu's Properties:

Albedo[4]: 0.045
Location[4]: Near- Earth (between orbits of Earth and Mars)
Eccentricity[1]: 0.204
Rotational Period[4]: 4.297 hours
Density[1]: 1.26 g/cm^3
Class[1]: B-type
Assumed Origin[4]: Sourced from the beginning of the solar system

Other asteroids have been studied much more extensively than Bennu. A cross-analysis with other more well known asteroids is valuable in broadening our understanding of Bennu. By comparing properties of various asteroids, we hope to shed light on similarities to Bennu and provide a broader perspective for the OSIRIS-Rex mission.

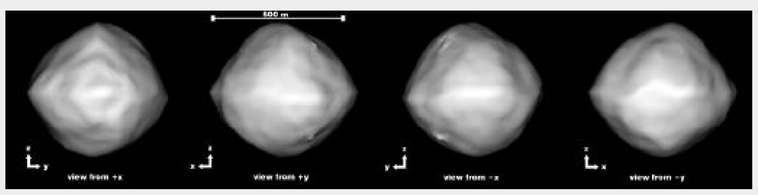


Figure 1: Bennu shape models, adapted from [2].

METHODS

1. Chose four asteroids to compare to Bennu: Pallas, Elpis, Themis, and Itokawa.
   Pallas, Elpis, and Themis
   Also B-type, so we expected them to have similar mineral compositions as Bennu.
   Itokawa
   A Near Earth Asteroid (NEA), like Bennu, so we expected it to have similar geological features.
2. Researched previous studies to find qualitative and quantitative data for each asteroid (see Citations).
3. Compared our findings to properties of Bennu.
4. Analyzed the data to determine the potential mineral compositions and physical properties scientists could expect to see on Bennu.

ACKNOWLEDGEMENTS

We would like to thank Dr. Ryan Clegg-Watkins for her assistance and guidance through our work. We would also like to to thank the Lunar & Planetary institute, the ExMASS program, and Dr. Andrew Shaner for their dedication to bringing academic science to the high school classroom.

RESULTS

The table below shows a comparison of various physical properties between the four selected asteroids and Bennu. Properties were determined from various sources (see Citations).

Y = Yes (there is a similarity)
N = No (no similarity)
- = No information found.

Property	Pallas	Elpis	Themis	Itokawa
Albedo	N	Y	Y	N
Location	N	N	N	Y
Eccentricity	Y	Y	Y	Y
Rotation	N	N	N	N
Density	N	Y	N	N
Class Type	Y	Y	Y	N
Origin	Y	-	N	-

Table 1: Comparison of various properties between Bennu & other asteroids.

CONCLUSIONS

Our data indicate that Bennu is most similar to Elpis The two asteroids are from the same class, and share a similar albedo and density. The similarity in these properties indicates similar origin and composition between Elpis and Bennu. Even though Themis is also a B-type asteroid, the only comparison that can be made between Themis and Bennu is the albedo, which may indicate they are compositionally similar and/or have similar physical surface properties. However, the densities between Themis and Bennu are significantly different, such that a better comparison can be made between Elpis and Bennu regarding density. Pallas is also a B-type asteroid, but is much larger than Bennu and varies more in density and albedo. Because of these differences, we conclude that Pallas has had a different evolutionary history than Bennu.

Itokawa is a completely different type of asteroid and has a slower rotation period than Bennu, making Itokawa the most unlike Bennu. We conclude that because of the many dissimilarities between Itokawa and Bennu, scientists can expect to find contrasting features during the OSIRIS-REx mission.

Although Elpis is most similar to Bennu, all similar properties between Bennu and other B-type asteroids should be valued. Bennu's evolutionary history likely includes physical changes due to encounters with other asteroids, or parts of Bennu separating, which would indicate many asteroids, both older and younger than Bennu, have similar properties. Individual similarities in properties could still indicate a comparable origin and history. OSIRIS-REx mission scientists can use information from these asteroids to make predictions about the properties of Bennu that are unclear from what is seen using telescopes from Earth.

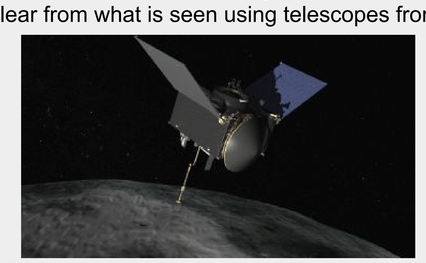
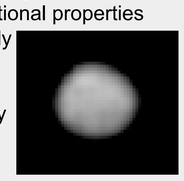


Figure 2: Concept art for OSIRIS-REx mission, from [4].

DISCUSSION

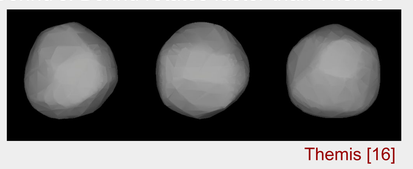
2 Pallas: Pallas is a B-Type asteroid with an albedo of 0.159[13], slightly higher than Bennu. Since Pallas and Bennu are the same type of asteroid, and they are both thought to be protoplanetary, Bennu is likely to have similar compositional properties as Pallas, e.g. silicates containing iron and water. Pallas has a slightly greater density (1.66 g/cm^3) than Bennu[11], indicating some compositional differences. Pallas has a larger semi-major axis, longer rotational period, and is part of the main belt.[13] However, they have extremely similar eccentricity(0.231 for Pallas).[13] Pallas has a smooth surface with several small craters[11], and we expect to see similar surface features on Bennu.



Pallas [15]

59 Elpis: Bennu and 59 Elpis have some differences, which is expected since they orbit different parts of the solar system[13]. Bennu is a NEA and Elpis occupies the main belt, so their orbits are not easily comparable. However, their eccentricities are fairly similar: Bennu's orbit has an eccentricity of 0.204 and Elpis' has one of 0.120.[13] Other notable similarities between Bennu and Elpis are density (1.26 g/cm^3 and 1.30 g/cm^3, respectively)[14] and albedo (.045 and .044, respectively)[13]. These characteristics are related to compositional properties, possibly hinting at a similar origin. Bennu is likely smaller than Elpis, as it has a much smaller mass[14] and a rotation period[13] about nine hours less than that of Elpis.

24 Themis: 24 Themis is a B-type asteroid with an albedo (0.067)[8] similar to Bennu's. This similarity indicates that Bennu and Themis likely have similar compositional and/or physical properties, and that Bennu may have organic material and water ice like Themis.[7] Bennu (NEA) and Themis (main belt) both orbit different areas of the solar system. However, Bennu's eccentricity is similar to Themis' eccentricity (0.126)[13], where Themis's orbit is more circular than Bennu's. Bennu rotates faster than Themis [13], indicating Bennu is smaller than Themis. Bennu's bulk density is much smaller than Themis' (2.78 g/cm^3)[8], supporting the idea that Bennu is smaller and/or contains different rock types.



Themis [16]

25143 Itokawa: Itokawa is an S-type asteroid. S-type asteroids are more silica-rich whereas B-type asteroids are more primitive and carbon-rich, so the composition of Bennu is very different.[12] Itokawa has has a slightly larger eccentricity than Bennu (by 0.08), so Itokawa's orbit is only slightly less circular than Bennu's orbit.[13] The rotation period of Itokawa is significantly slower than that of Bennu.[13] Itokawa is slightly more dense (1.90 g/cm^3)[13] than Bennu, however Bennu is significantly more massive. Itokawa is shaped like a peanut[12], and Bennu is more spherical. Both Itokawa and Bennu are NEAs and have similar locations within our solar system[13]. However, based on their compositions, their origins are likely very different.

Itokawa [17]

CITATIONS

[1] Lauretta et al. (2015) The OSIRIS-REx target asteroid (101955) Bennu: Constraints on its physical, geological, and dynamical nature from astronomical observations. *Meteoritics & Planetary Science* 50, Nr 4, p. 834–849
[2] Nolan et al. (2013) Shape model and surface properties of the OSIRIS-REx target Asteroid (101955) Bennu from radar and lightcurve observations. *Icarus* 226, Issue 1, p. 629–640
[3] Hergenrother et al. (2013) Lightcurve, Color and Phase Function Photometry of the OSIRIS-REx Target Asteroid (101955) Bennu. *Icarus* 226, Issue 1, p. 663–670
[4] Beshore et al. (2015) The OSIRIS-REx Asteroid Sample Return Mission. *IEEE 2015 Aerospace Conference*.
[5] Chelsey et al. (2014) Orbit and bulk density of the OSIRIS-REx target Asteroid (101955) Bennu. *Icarus* 235, p. 5–22
[6] Clark et al. (2014) Asteroid (101955) 1999 RQ36: Spectroscopy from 0.4 to 2.4 um and meteorite analogs. *Icarus* 216, Issue 2, p. 462–475
[7] Campins et al. (2010) Water ice and organics on the surface of the asteroid 24 Themis. *Nature* 464
[8] Castillo-Rogez & Schmidt (2010) Geophysical evolution of the Themis family parent body. *Geophysical Research Letters* 37
[9] Larson, Feierberg, & Lebofsky (1983) The Composition of Asteroid 2 Pallas and Its Relation to Primitive Meteorites. *Icarus* 56, p. 398-408
[10] De Leon et al. (2012) Near-infrared spectroscopic survey of B-type asteroids: Compositional analysis. *Icarus* 218, p. 196-206
[11] Hudson et al. (1996) Radar Observations of Asteroids 1 Ceres, 2 Pallas, and 4 Vesta. *Icarus* 124, p. 113-133
[12] Tsuchiyama (2014) Asteroid Itokawa: A source of ordinary chondrites and a laboratory for surface processes. *Elements* 10, p. 45-50
[13] JPL Small-Body Database. http://ssd.jpl.nasa.gov/sbdb.cgi
[14] Carry (2012) Density of asteroids. *Planetary and Space Science* 73, p. 98–118
[15] Pallas image from Hubble Space telescope, in Schmidt et al. (2008)
[16] Themis image from light curve analysis of Hanuš et al. (2016)
[17] Itokawa image from JAXA.