Asteroid (142) Polana at 3 μm and its Connection to Primitive Near-Earth Asteroids

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Introduction: Impacts between asteroid-sized objects have dominated the solar system's history and played a significant role in forming asteroid families. The New Polana family is a low-inclination and the most prominent low-albedo family within the inner Main Belt between the v_6 secular resonance at ~2.0 AU and the 3:1 mean-motion resonance with Jupiter at ~2.5 AU [1]. This family formed over 2000 Myr ago and is parented by the B-type asteroid (142) Polana [1]. [2] and [3] found that primitive near-Earth asteroids (NEAs), including Hayabusa2's asteroid target (162173) Ryugu and OSIRIS-REx's asteroid target (101955) Bennu, are likely disrupted fragments that originated during the formation of the New Polana family. Other possible sources of primitive NEAs in the inner Main Belt include the Clarissa, Erigone, Polana, and Sulamitis, families and the collisionally evolved background asteroids outside these families [2, 4].

The age of the solar system is longer than the collisional lifetime of asteroid Bennu [5], a rubble pile asteroid with a mean diameter of 490.06 ± 0.16 m [6] and a spinning top-like shape [7]. Asteroid 142 Polana, the largest remnant of the New Polana family [1], has been spectrally (~0.5-2.5 μm) and dynamically linked to asteroid Bennu [e.g., 2]. Bennu's spectra were measured over the wavelength range from 0.4 to 4.3 μm with OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS) [8]. Here, we investigate the compositional linkage of asteroids Polana and Bennu using 3-μm Polana spectra measured at the Infrared Telescope Facility (IRTF).

Results: Polana's prism (0.7- 2.5 μm) spectra exhibit a broad concave feature centered ~1.21 μm with a band depth of ~11%. The spectrum has a slight positive slope toward wavelengths greater than 1.2 μm. We acquired two Prism sets of Polana, the first at 12:32 UTC and the second at 12:48 UTC on July 2nd, 2023. Spectra of the two prism sets are similar, showing no compositional heterogeneity in the observed surface of Polana. On the other hand, Polana's LXD (1.9– 4.2-μm) spectra do not reveal any pronounced spectral features in the ~2.0-4.0-μm spectral range, suggesting that this asteroid is not hydrated (Figure 1).

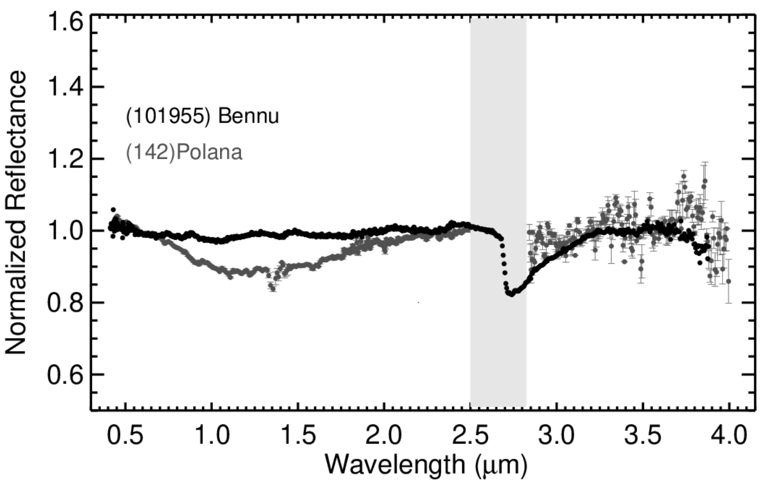

Figure 1. Spectra of asteroids Bennu and Polana. The ~1.2-μm band in Polana is more pronounced than in Bennu. Bennu's spectrum is an average spectrum measured at the 10:00 a.m. station. Unlike Bennu, Polana does not show a pronounced feature at ~3-μm. Slope-removed spectra are normalized at 2.2 μm.

Discussion: Prism's spectrum of Polana shows a broad feature centered around 1.2 μm (Figure 1), possibly due to amorphous iron-rich silicates abundant in least-processed CO carbonaceous chondrites that experienced minimal aqueous alteration and thermal metamorphism [10, 11]. Magnetite was also suggested to cause the 1.2-μm feature in B-type asteroids [12]. The 1.2-μm feature in the Polana spectrum is much deeper and more pronounced than Bennu's, suggesting that Polana has more abundant amorphous silicates or magnetite on its surface than Bennu. Polana was previously observed by [13], and its spectra SNR did not allow the authors to confirm the presence of a feature at ~3-μm. In this work, the LXD spectrum of Polana was found to be featureless (does not exhibit a 3-μm feature within two sigma), suggesting that Polana's surface is much less hydrated than Bennu's. Bennu's spectra were measured by OSIRIS-REx's OVIRS spectrometer, revealing that this primitive asteroid is hydrated (the 3-μm band has a depth of ~20%) consistent with CM-, CI-, or CR-type carbonaceous chondrites [9]. In addition, Polana's LXD spectra do not indicate the presence of organics and/or carbonates, unlike Bennu, whose spectra were found to be consistent with carbonates dominated by calcite and aromatic and aliphatic organics with CH bonds [14, 15].

The lack of pronounced water (OH/H_2O), organic materials, and carbonates features on asteroid Polana could be related to the degree of heating produced by shock metamorphism during the New Polana family-forming event and the ejecta reaccretion that contributed to additional heating. To lose most of its surface hydrated minerals, including serpentines, Polana had to be exposed to impact temperatures higher than ~800 K [16]. Heating generated by disruptive collisions (families forming events) is substantial, where the temperature of almost all the parent bodies increases from 300 K (initial temperature) to 700 K [17]. [18] concluded that the hydration state of the members of a collisional family is heterogeneous and mainly depends on the impact energy level within the family.

Several factors can affect the degree of heating and shock metamorphism during family-forming events, including the impactor velocity and size, porosity within the asteroid's parent body, and material ejection efficiency. [19] found that in rubble-pile asteroids, the impactor velocity and size are the main factors responsible for high-grade shock metamorphism in impacts occurring in the Main Belt. According to these authors, changing the porosity, responsible for the overall energy absorption within the parent body, from 10% to 30% in their simulations only slightly decreases the shock pressure and temperature.

Another possibility for explaining the discrepancy between Polana and Bennu in the 3-µm band could be that the New Polana family-forming event exposed the parent body's deep interior. The dislodged Bennu fragment from the parent body contains phyllosilicates, organics, and carbonate, unlike the exposed interior of the parent body that does not include these materials.

Laboratory experiments on carbonaceous chondrites have shown that space weathering can also affect the spectral characteristics of these chondrites [20, 21]. For example, irradiating these carbonaceous chondrites can cause their near-infrared spectra to become bluer and brighter or redder and darker depending on several factors, including their initial albedo. Space weathering can also cause the band depth of mineral absorptions at 0.7 and 3.0 µm to decrease receptively by 12 % to 50% [22]. Space weathering could cause the band depth at 3.0 µm to degrade significantly over time. The New Polana is one of the older families in the Main Belt (~2000 Myr, [1]). Near-Earth asteroids' lifetimes are ~10 Myr [3]; therefore, Bennu would have been less exposed to space weathering than Polana was.

Exogenic materials and breccias are common in NEAs (e.g., [23]). Exogenous basaltic materials were discovered on the rubble pile asteroid Bennu, linked to inter-asteroid mixing that occurred at macroscopic scales after the end of the planetesimal formation [24]. It is possible that exogenic hydrated (in addition to basaltic) materials landed on Bennu, contributing to its hydration level.

Remote sensing observations of the primitive NEAs Ryugu and Bennu suggested that these two asteroids experienced different aqueous alteration histories, as revealed by the characterization of their surface composition using the 3-µm band. The NIRS3 instrument on board hayabusa2 detected a weak and narrow absorption feature centered around 2.27 µm across the observed Ruguy's surface, attributed to hydroxyl-bearing minerals [25]. Returned samples from Ryugu confirmed that this asteroid has a similar composition to CI-type carbonaceous chondrites [26]. OSIRIS-REx's OVIRS detected a broader and deeper 3-µm band in Bennu compared to NIRS3 observations of Ryugy. Based on their 3-µm hydration features, it is more likely that Ryugu and Bennu came from different parent bodies with distinct aqueous alteration and thermal histories. With the current ground-based observations of Polana and due to strong Earth atmospheric absorptions that affect the ~2.7-µm region, it is not feasible to fully assess if this asteroid has a 3-µm band like the narrow and subtle band found in Ryugu. An approved JWST program to observe Polana (with the NIRSpec and MIRI instruments) will allow us to further investigate Polana's connection to Bennu and Ryugu.

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