Hypothesizing the Existence of Zhuque Family in the 5:2 Kirkwood Gap

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INTRODUCTION

Rocky asteroids bodies between Mars and Jupiter (2.2 and 3.2 AU) are remnants from early solar system formation events. Similarly composed asteroids with close orbits hint at their contemporary existence, such as the Vesta family of asteroids. Vestoids vary relatively little in their mineralogical compositions and orbital parameters.

This study investigates the plausibility that a planet body existed within the 5:2 Kirkwood gap, an area with gravitational resonance with Jupiter that prevents bodies big and small from residing in that particular orbit. To identify the asteroids within the family, band centers from 17 asteroids in the area that could have been the final resting place of the disrupted parent body were collected and used to predict olivine/forsterite composition, and see if the compositions indicate whether the different observed bodies could be genetically related.

METHODS

Seven M-, six A- and four V-type asteroids near the 5:2 Kirkwood gap but outside the Vestoid range of 2.25 to 2.45 AU were identified based on semimajor axis (2.5 to 3.2 AU), eccentricity (0.03 to 0.3), inclination (0 to 30 deg) and diameter data from the JPL Small Body Database as well as the availability of spectroscopy data. Target asteroids are 216 Kleopatra, 16 Psyche, 1210 Morosovia, 22 Kalliope, 347 Pariana, 558 Carmen, 798 Ruth; 863 Benkoela, 446 Aeternitas, 289 Nenetta, 246 Asporina, 354 Eleonora 3819 Robinson; 1459 Magnya, 10537 1991 RY16, 21238 Panarea, and 7472 Kumakiri.

Corrected band center data at ~0.9 µm (B-I) and ~2.0 µm (B-II) for V-type asteroids, and ~1.0 µm (B-I) data for A-type asteroids was obtained from various research papers. These band centers were determined from modifying a spectral reflectance curve and fitting the minimum values into a polynomial equation. Mineralogical compositions were estimated using linear calibration,ns of pyroxene mol% vs BIC developed by [1] and [2] and similar linear calibrations of olivine mol% vs BIC developed by [3]. For example, the equation of the linear fit for olivine is

$$Fo = -1946.6 \times (BIC) + 2139.4$$

Fo mol% for A-type asteroids and Fs mol% for V-type asteroids were calculated using these equations.

DATA AND RESULTS

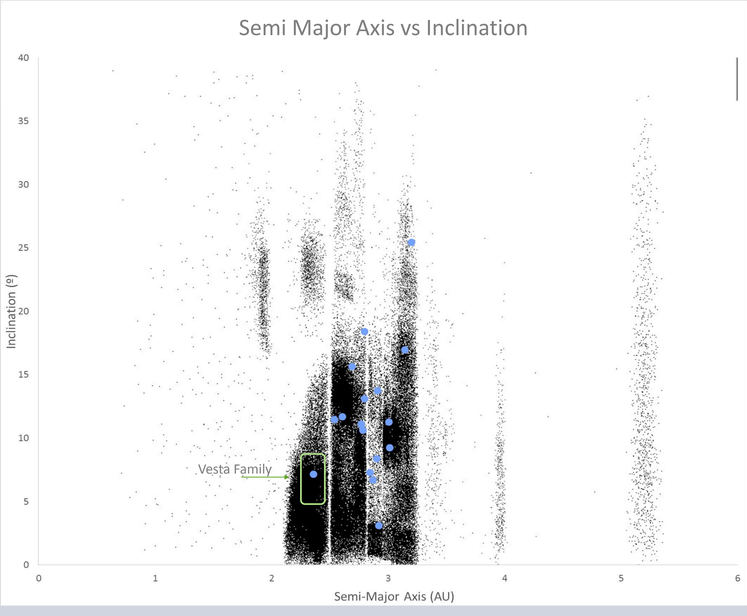

Fig. 1. Semimajor axis versus inclination distribution of target asteroids in relation to other asteroids compiled in the Minor Planet Center orbit database. Vesta is situated left of the 3:1 resonance, with family range shown in box, while the 17 target asteroids are centered around the 5:2 Kirkwood Gap and lie close proximity to one another.

***Zhuque**, the Vermilion Bird of the South, is one of the four ancient Chinese constellation creatures. As Bellaire's mascot is a slightly less majestic cardinal, we thought our asteroid family would benefit from having the name of Zhuque.*

Table 1a. V-type asteroids as basaltic crust

Name (V-type)	Temperature-corrected Band centers	[Fs]	% difference from 4 Vesta	Part of Zhuque?
1459 Magnya[d]	BIC = 0.926 BIIC =1.938	36 ± 5[1]	- 22%	√
10537 (1991 RY16) [e]	BIC = 0.96 BIIC = 1.91	37 ± 5[1]	- 20%	√
21238 Panarea[a]	BIC = 0.93 BIIC = 1.89	23 ± 5[1]	- 50%	√
7472 Kumakiri[g]	BIC = 0.934	42 ± 3[2]	0%	X
4 Vesta[b]	BIC = 0.936 BIIC = 1.969	42 ± 3[2] 46 ± 5[1]	0% 0%	X

Table 1b. A-type asteroids as olivine mantle

Name (A-type)	Corrected Band I Center[f]	[Fo][3]	Part of Zhuque?
863 Benkoela	BIC = 1.059	77.9506	√
446 Aeternitas	BIC = 1.066	64.3244	√
289 Nenetta	BIC = 1.069	58.4846	√
246 Asporina	BIC = 1.065	66.271	√
354 Eleonora	BIC = 1.060	76.004	√
3819 Robinson	BIC = 1.055	85.737	√

[1] (Gaffey et al., 2002)
[2] (Burbine et al.,2009)
[3] (Reddy et al., 2011)
[a] (Burbine et al, 2008)
[b] (Gaffey, 1997)
[c] (Hardersen et al., n.d)
[d] (Hardersen et al, 2004)
[e] (Moskovitz et al., 2008)
[f] (Sanchez et al., 2013)
[g] (Solontoi et al, 2012)

Table 1c. M-type asteroids as NiFe core

Name (M-type)	Composition[1,c]	Part of Zhuque?
216 Kleopatra	NiFe metal	√
16 Psyche	NiFe metal	√
1210 Morosovia	Olivine bearing metal	√
22 Kalliope	Pyroxene bearing metal	√
347 Pariana	Pyroxene bearing metal	√
558 Carmen	Pyroxene bearing metal	√
789 Ruth	Olivine Bearing metal	√

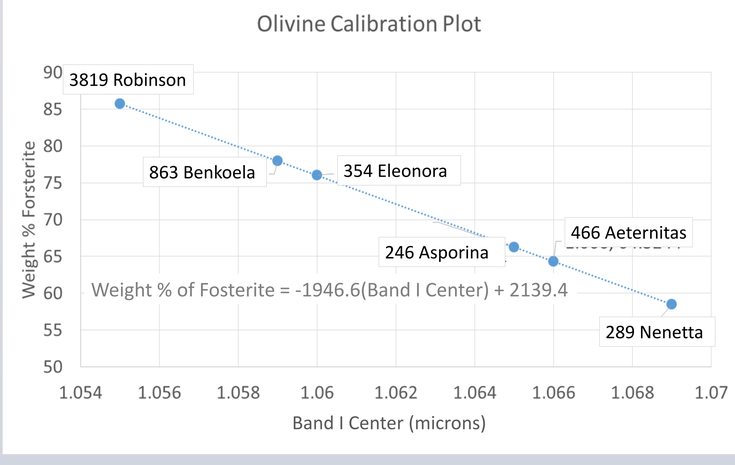

Fig. 2. Band centers (indicated in Table 1b.) versus weight percent forsterite of the olivine dominated A-type asteroids extrapolated from the linear relationship between the two as found in meteorites. [3]

DISCUSSION

The orbital data and mineralogical compositions indicate the plausibility of a disrupted parent body at the 5:2 Kirkwood gap. Sixteen asteroids center around this gap and form a part of the Zhuque family, which originally contained less Fs than 4 Vesta and thus could have formed in a more chemically reduced region of the solar system.

These asteroids exhibit a greater range of inclinations than the Vesta family, either due to earlier disruption and the lack of a parent body to gravitationally attract related fragments or due to gravitational interactions with other planets that has timescales of 1-10 million years. Nice 2 Model also suggests that when Jupiter and Saturn's orbits spread apart, outer-belt asteroids were more affected than the inner-belt Vesta family. Furthermore, because fragments larger than 3 km in diameter are unlikely to cross the 3:1 resonance, and the asteroids studied have diameters between ~5-255 km, they most likely did not originate from Vesta.

Sixteen out of 17 asteroids originate from the proposed parent body. The 6 A-type asteroids show forsterite molar percentages between Fo 56-86, confirming olivine-dominated compositions that correspond to the mantle of a differentiated body. Three of the basaltic V-type asteroids have ferrosilite molar percentages ranging from Fs 23 to Fs 37, showing significant differences of ~20 mol% less Fs than 4 Vesta. These results, combined with the confirmed NiFe compositions of the M-type asteroids from [1], agree with Fieber et al's differentiation model [4] and strongly suggest that these asteroids can be the remnants of a disrupted protoplanet at the 5:2 Kirkwood gap. The exception, 7472 Kumakiri, is mineralogically similar to Vesta with overlapping error bars in Fs mol%.

CONCLUSIONS

Orbital and mineralogical characterizations from this study suggest the presence of a family of asteroids, the Zhuque family, located near the 5:2 Kirkwood gap during the early solar system. Once the protoplanet Zhuque was captured in 5:2 resonance during Jupiter's migration into the inner solar system, as envisioned by the Grand Tack model, gravitational tidal forces probably caused Zhuque's disruption.

This study sheds light on possible scenarios in solar system formation and on the evolution of asteroid belts. Further investigations can involve:

- Identifying more asteroids in the Zhuque family, especially rare A-type mantle material and V-type crust material in the outer belt
- Determining if any E-type asteroids originate from Zhuque's mantle to better characterize the parent body
- Identifying meteorite analogs among HED meteorites and Mg-rich olivine meteorites
- Modeling the disruption of Zhuque and the time-evolution of the remnants

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