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15 Eunomia and collisional family as the source of ureilites

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Abstract

We argue that ureilites (C-rich achondrite meteorites) derive from the collisional family of 15 Eunomia. We discuss evidence that ureilites are mixtures of materials from the ureilite parent body (UPB) and an impactor, and we use this information to derive their properties. We show that 15 Eunomia and its collisional family are consistent with these properties. We discuss a dynamical pathway by which the Almahata Sitta polymict ureilite may have been delivered to Earth from the Eunomian family.

1. Introduction

Ureilites (see review by [1]) are an unusual type of meteorite. Despite being the second most common achondrite, no asteroid has been suggested as ureilite parent body (UPB). Ureilites are extremely (~3wt%) carbon-rich and are sometimes associated with carbonaceous chondrites from the outer solar system; but isotopically they are constrained to have formed in the inner solar system [2]. The general trend of ^{54}Cr anomaly versus distance from the Sun suggests they formed at 2.72-2.80 AU [3]. Identifying the source of ureilites would unravel many mysteries about the origin of the solar system.

A clue to the origins of ureilites comes from the numerous reduction rims and metal blebs around olivine grains in contact with graphite, which are widely accepted to have formed when the pressure was suddenly released, allowing C to react with Fe in silicates, followed by a quenching of the reaction by rapid cooling [1]. The UPB is inferred to have been catastrophically disrupted, shattered into boulders ≤ 10 m in size that reassembled into a series of ureilite daughter bodies (UDBs) [4]. Radiometric dating suggests this collision occurred about 5 Myr into solar system history [1]. Based on this, ureilites likely derive from an ancient collisional family.

The Almahata Sitta meteorites fell in Sudan in October 2008, after being observed in space as the asteroid 2008 TC_3 [5]. The asteroid was assessed to have been injected onto an Earth-crossing orbit by passage through either the ν6 resonance at 2.05 AU (80% probability) or the 3:1 resonance at 2.50 AU (20% probability) [5]. Spectrally this asteroid was classified as F type, so a collisional family of F-type asteroids was sought, but all five identified families are inconsistent with ureilites (especially age) [5].

We use insights into ureilites to identify their source as the collisional family of 15 Eunomia.

2. Ureilites

Most ureilites are monomict, with olivines with a uniform Mg# within a given meteorite. The distribution of Mg# across all ureilites varies from 74 to 96, with a strong peak near Mg#80 [1]. About 5% of ureilites are polymict and have within them olivines across that entire range. Almahata Sitta, notably, is polymict and therefore does not represent the majority of ureilites. Ureilites traditionally have been linked to asteroids of spectral type S(I), S(II), S(III), or S(IV) [6]. Ureilites probably derive from an ancient collisional family of S-type asteroids.

Ureilites, we argue, contain exogenous materials. The anomalously high C content is most easily explained as exogenous, and the graphite has large (100 μm) diamonds that arguably formed at pressures > 4 GPa [7]. Highly siderophile element (HSE) patterns in ureilite metal are explained as mixtures of two metals [8,9]. We suggest ureilites also contain exogenous silicates from the impactor. Many properties correlate with olivine Mg# [1,10]. We tentatively suggest that olivines with Mg#<80 differ from those with Mg#>80 (e.g, in δ^{13}C [10], Cr valence [11], and noble gases [12]); we attribute the ~25% of silicates with Mg#<80 to the impactor. The remarkably large range of Mg# in ureilite olivines has been attributed to pressure-sensitive 'smelting' reactions like $(Fe,Mg)_2SiO_4$ + CaO (melt) + SiO_2 (melt) + C → 2 $(Ca,Mg)SiO_3$ + Fe + CO (gas) [13]. Olivine Mg# would then correlate with depth; this model suggests a radius ~170 km for the UPB. Assuming impactor silicates are sampled with equal efficiency, the impactor would have radius ~115 km.

3. Asteroid 15 Eunomia

We speculate the impactor was a fragment of Mars, ejected during the Borealis basin impact, similar to olivine-rich A-type asteroids [14]. Such fragments would reach distances of up to 2.9 AU, colliding with asteroids at typical speeds ~5 km/s. Based on our inferred masses and this impact speed, we use the formulas of [15] to estimate the largest fragment would have radius ~135 km.

These properties match the S(III)-type, 132 km radius asteroid 15 Eunomia at 2.64 AU. It has an extensive and ancient (several Gyr) collisional family [16]. The ν6-ν5+ν16 secular resonance can transport family members to 2.55 AU, *i*~8° [16]. The F-type asteroid 438 Zeuxo orbits at 2.55 AU, *i*~7.4°. We suggest it is a family member and also the source of 2008 TC_3, which could have Yarokvsky drifted to the 3:1 resonance at 2.50 AU within the cosmic-ray exposure age 20 Myr [5]. The compositions of the family members are consistent with them being the source of ureilites, as depicted in Figure 1.

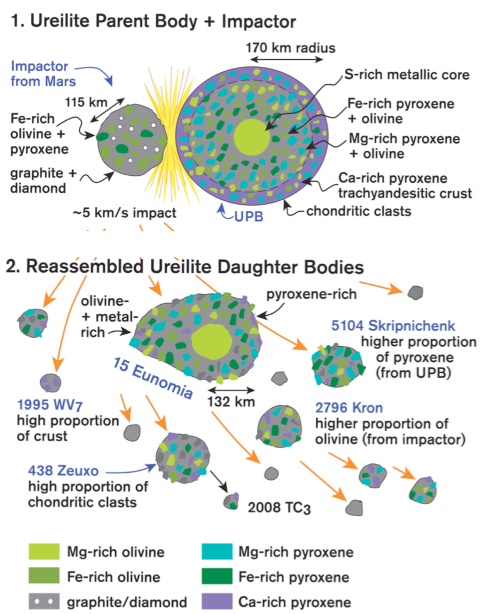

Figure 1: Our hypothesized relationship of the Eunomian collisional family to ureilites.

References

[1] Goodrich, C. et al.: Origin and history of ureilitic material in the solar system: The view from asteroid 2008 TC3 and the Almahata Sitta meteorite, *Meteorit. Plan. Sci.* 50, 782-809, 2015.

[2] Warren, P.H.: Stable isotopes and the noncarbonaceous derivation of ureilites in common with nearly all differentiated planetary materials, *Geochim. Cosmochim. Acta* 75, 6912-6926, 2011.

[3] Yamakawa, A. et al.: Chromium isotope systematics of achondrites: chronology and isotopic heterogeneity of the inner solar system bodies, *Ap. J.* 720, 150-154, 2010.

[4] Herrin, J. S., et al.: Thermal and fragmentation history of ureilitic asteroids: Insights from the Almahata Sitta fall, *Meteorit. Plan. Sci.* 45, 1789-1803, 2010.

[5] Jenniskens, P. et al.: Almahata Sitta (=asteroid 2008 TC_3) and the search for the ureilite parent body. *Meteorit. Plan. Sci.* 45, 1590-1617, 2010.

[6] Gaffey, M. J., et al.: Mineralogical variations within the S-type asteroid class. *Icarus* 106, 573-602, 1993.

[7] Miyahara, M. et al.: Unique large diamonds in a ureilite from Almahata Sitta 2008 TC_3 asteroid. *Geochim. Cosmochim. Acta* 163, 14-26, 2015.

[8] Rankenberg, K. et al.: Highly siderophile elements in ureilites, *Geochim. Cosmochim. Acta* 72, 4642-4659, 2008.

[9] Goodrich, C. and Desch, S. J.: Exogenous metal in ureilites, 82nd Annual Mtg of the Meteoritical Society 2019.

[10] Barrat, J.A. et al.: Carbon isotopic variation in ureilites: Evidence for an early, volatile-rich inner solar system. *Earth Plan. Sci. Lett.* 478, 143-149, 2017.

[11] Goodrich, C. et al.: Chromium valence in ureilite olivine and implications for ureilite petrogenesis. *Geochim. Cosmochim. Acta* 122, 280-305, 2013.

[12] Rai, V. K., Murty, S. V. S. and Ott, U.: Noble gases in ureilites: cosmogenic, radiogenic, and trapped components, *Geochim. Cosmochim. Acta* 67, 4435-4456, 2003.

[13] Singletary, S.J. and Grove, T.L.: Early petrologic processes on the ureilite parent body. *Meteorit. Plan. Sci.* 38, 95-108, 2003.

[14] Hyodo, R. and Genda, H.: Implantation of martian materials in the inner solar system by a mega impact on Mars. *Ap.J.* 856, L36-41, 2018.

[16] Leinhardt, Z. M. and Stewart, S. T.: Collisions between gravity-dominated bodies. I. Outcome regimes and scaling laws. *Ap. J.* 745, 79-105, 2012.

[17] Carruba, V., et al.: Dynamical evolution of V-type asteroids in the central main belt. *Mon. Not. Roy. Astron. Soc.* 439, 3168-3179, 2014.