

Dawn's GRaND to map the chemical composition of asteroids Vesta and Ceres

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The NASA Dawn spacecraft is approaching the main asteroid belt, where it will acquire data needed to understand processes underlying the formation and evolution of the terrestrial planets [1]. Using ion propulsion, Dawn will explore asteroid 4 Vesta, arriving in 2011, followed by the dwarf planet 1 Ceres in 2015. Vesta and Ceres are complementary: Vesta is dry and underwent igneous differentiation to form a crust, mantle, and core [2]; whereas, Ceres underwent aqueous differentiation, and may contain subsurface liquid water [3]. Dawn will acquire remote sensing data to determine shape, gravity field, mineralogy, geochemistry, and surface morphology. Dawn's payload includes framing cameras, a visual-infrared spectrometer, and a gamma ray and neutron detector (GRaND).

GRaND will determine the abundances of rock forming elements, such as Fe, Si, and Mg, and the abundances of light elements, including H, C, and N, found in ices and in products of aqueous alteration and space weathering. GRaND will test the widely accepted theory that Vesta is the source of the achondrites, measure compositional layering to determine how Vesta differentiated (fractional crystallization of a magma ocean vs. serial magmatism), and search for compositions not well-represented in the meteorite collection [4, 5]. At Ceres, GRaND will provide constraints on the inventory of crustal water and organics, detect aqueous alteration products (e.g. [6]), and search for remnants of the primitive crust. In this prospective study, we use modeling, validated with data acquired during cruise and Mars Gravity Assist, to describe how GRaND will constrain the geochemistry of Vesta and Ceres.

[1] Russell *et al.* (2004) *PSS* **52**, 465-489. [2] Keil (2002) In *Asteroids III*, 573-584. [3] McCord & Sotin, *JGR* **110**, E05009, doi:10.1029/2004JE002244. [4] Barrat *et al.* (2009) *MAPS* **44**, 359-374. [5] Beck & McSween (2009) LPS XL, CD #1127. [6] Milliken & Rivkin (2009), *Nature Geoscience* **2**, 258-261.

Carbonate clumped-isotope paleothermometry of sub-Arctic early Cretaceous fossils

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Here we present estimates of sub-Arctic marine temperatures from Cretaceous belemnites using 'carbonate clumped-isotope' paleothermometry. The early Cretaceous (Valanginian) material is from the Yatria River, sub polar Urals, Siberia, paleolatitude of ~60-65°N. The ¹³C-¹⁸O bond enrichment in these shells ranges between 0.64 and 0.67‰ (Δ_{47}), implying shell growth temperatures of 20-26°C. Present temperatures at this latitude are typically less than 5°C, and our data are consistent with independent evidence of a warm 'greenhouse' world featuring a shallow latitudinal temperature gradient, and possibly the absence of ice in the high latitudes. However, there are important issues to be addressed in our use of this relatively new isotopic system. The combined temperature and $\delta^{18}\text{O}$ -carbonate data imply average seawater $\delta^{18}\text{O}$ values of 0.5 to 1.5‰. This is higher than the expected range for high latitude Cretaceous seawater, although such values are plausible and may point to unexpected basin- or global-scale hydrologies in the early Cretaceous. However, we also consider 1) diagenetic reordering of ¹³C-¹⁸O bonds in a closed system, 2) belemnite body fluid in isotopic disequilibrium with seawater, and 3) intercalibration issues and the existing Δ_{47} -temperature calibration for these measurements. Of these, (2) should not influence clumped isotope paleotemperatures, and we estimate the effects of (3) as less than a few degrees. The combined Δ_{47} and $\delta^{18}\text{O}$ data rule out isotopic exchange with high temperature fluids in deep burial environments, as well as late diagenesis in the presence of meteoric waters. The isotopic data are consistent with primary marine environments, or early diagenesis in shallow burial environments. We suggest that actual marine temperatures can be conservatively bracketed between traditional $\delta^{18}\text{O}$ -in-carbonate temperatures (assuming $\delta^{18}\text{O}_{\text{water}} = -1.0\text{‰}$) and carbonate clumped-isotope temperatures. This translates to ca. 5-23°C for samples with the highest $\delta^{18}\text{O}$ (carb) values, and 15-26°C for those with the lowest values.