PLANETARY SCIENCE RESEARCH PSRD Discoveries

Hot Idea November 27, 2007

Getting to Know Vesta

--- Scientists are primed with geochemical data from HED meteorites for Dawn's encounter with asteroid 4 Vesta.

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The howardite-eucrite-diogenite class of meteorites (called the HEDs) are rocks formed from basaltic magmas. What makes them special is that the HEDs have reflectance spectra in the visible and near-infrared that match spectra from asteroid 4 Vesta, implying Vesta is their parent body. We will soon have new data from Vesta from NASA's Dawn orbiting spacecraft, which carries a gamma ray and neutron detector, dubbed the GRaND instrument. GRaND will orbit asteroid 4 Vesta and dwarf planet Ceres and map the near-surface abundances of major and minor elements, and volatiles found in ices (in the case of Ceres) such as hydrogen, carbon, nitrogen, and oxygen. Tomohiro Usui and Harry Y. (Hap) McSween, Jr. (University of Tennessee) have proposed a way to interpret the upcoming GRaND data from Vesta based on well-analyzed samples of HED meteorites and a mixing model they devised that uses element ratios of the three expected rock types. In turn, the new data from Vesta may help scientists better understand the geologic context for HED meteorites.

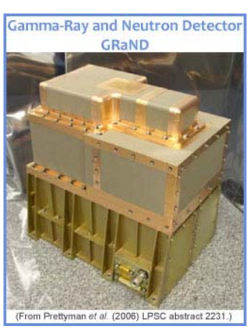
Reference:

- Usui, T. and McSween, Jr., H. Y. (2007) Geochemistry of 4 Vesta based on HED meteorites: Prospective study for interpretation of gamma ray and neutron spectra for the Dawn mission. *Meteoritics and Planetary Science*, v. 42, p. 255-269.

PSRDpresents: Getting to Know Vesta --Short Slide Summary (with accompanying notes).

Cosmochemistry of Vesta from Orbit

How do you take the grand idea of sending a spacecraft out to explore the asteroids and make it even better? Add a GRaND science instrument. (Sorry. I love the fact that creating acronyms is a favorite diversion for certain scientists.) The Gamma Ray and Neutron Detector instrument (GRaND) is one of three science payload instruments on NASA's Dawn Mission, which launched on September 27, 2007. GRaND will measure elemental compositions of the surface of asteroid Vesta (beginning in 2011) and dwarf planet Ceres (in 2015).

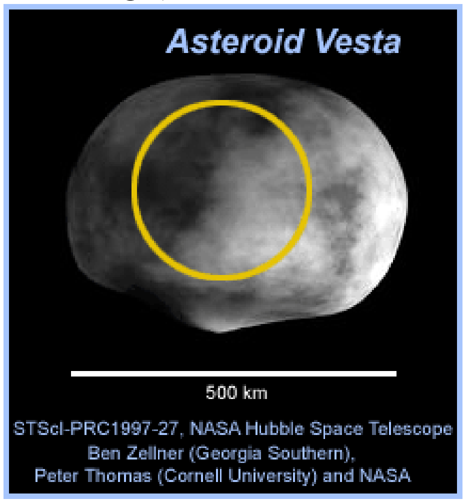


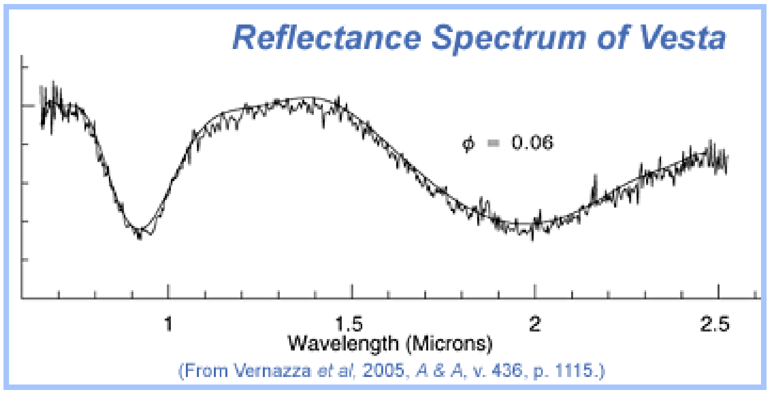
The GRaND instrument onboard NASA's Dawn spacecraft is 26 x 19 x 26 centimeters, see image on the left. This device was developed and is run by scientists from the Los Alamos National Laboratory. It consists of 21 sensors for high resolution gamma ray spectroscopy and neutron detection. It also carries analog and digital signal processing electronics, and low- and high-voltage power supplies.

GRaND uses 21 sensors to measure the energy from gamma rays and neutrons that are reflected or emitted by the different elements on the target body's surface and down to a depth of one meter. Scientists will make a global elemental map of Vesta to show where elements exist and in what abundances. They are particularly interested in mapping major elements (Si, Fe, Ti, Mg, Al, Ca) and minor elements (K, Th, U) on Vesta. The beauty of the minor elements is that they track the melting that led to the formation of the crust of the body during differentiation.

Our Knowledge about Vesta's Rocks

What we know about Vesta, let's call it pre-Dawn knowledge, is assembled from ground-based and Earth-orbiting telescopic spectra of its surface. Vesta is a dry, differentiated body that resembles the rocky bodies of the inner solar system, including Earth. Vesta's surface is basaltic, rich in the minerals pyroxene and plagioclase (see the reflectance spectrum below, right).





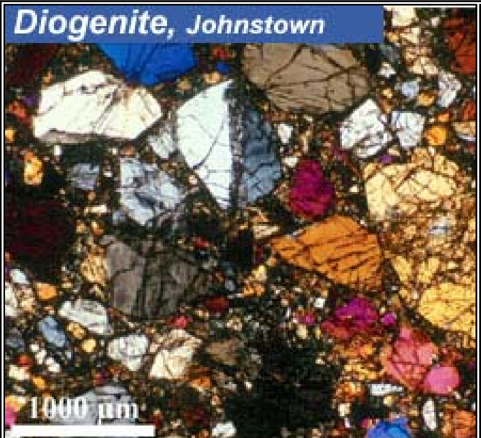
On the LEFT is a shaded image of Vesta created from Hubble Space Telescope topographic data. The gold circle superimposed on the image shows the best spatial resolution (~300 kilometers in diameter) GRaND will achieve during its low-altitude mapping orbit. On the RIGHT is a spectrum of Vesta obtained at the NASA Infrared Telescope Facility on Maunakea, Hawai'i by scientists in France using remote control networks from the Observatoire de Paris-Meudon. In particular, it is the presence of the 0.9 and 1.9 micrometer absorption bands for pyroxene in the spectra of Vesta that match spectra of the HED meteorites.

Based on Vesta's pyroxene mineralogy and what they know about achondrite meteorites, scientists expect Vesta's surface to be a mixture of three rock types: diogenites, basaltic eucrites, and cumulate eucrites. First a little word about these types and how they form. They are rocks, rich in pyroxene, that crystallized from magmas. Different minerals crystallize at different times during cooling in a magma chamber. Mineral crystals that form early and are more dense than the surrounding magma can sink and form piles on the floor of a magma chamber. Rocks formed from these piles of accumulated crystals are called cumulates. So when you see a cumulate rock you know it's a product of an over abundance of a particular mineral, such as pyroxene. Diogenites are such a rock; they are cumulates that formed at depth, made mostly of magnesium-rich, calcium-poor orthopyroxene. Eucrites have basaltic compositions with iron-rich pyroxene and sodium-poor plagioclase and may have formed from surface or near-surface lavas or as cumulates. Scientists think some basaltic eucrites were later metamorphosed by heat. Together with howardites, which are breccias of fragments of eucrites and diogenites, these rock types are known collectively as the howardite-eucrite-diogenite meteorite class or HEDs.

Once the Dawn spacecraft reaches Vesta, GRaND data will be used to make global maps of elemental abundances. The best spatial resolution will be about 300 kilometers per pixel (see Vesta image above). This is larger than the ~50-kilometer resolution Hubble data that already showed variability in composition of Vesta's surface. And it is far larger than the centimeter-size compositional variations in HED meteorites. Because of GRaND's coarse spatial resolution, Usui and McSween expect, and are prepared to interpret, data that mimic the mixing of HED meteorites.

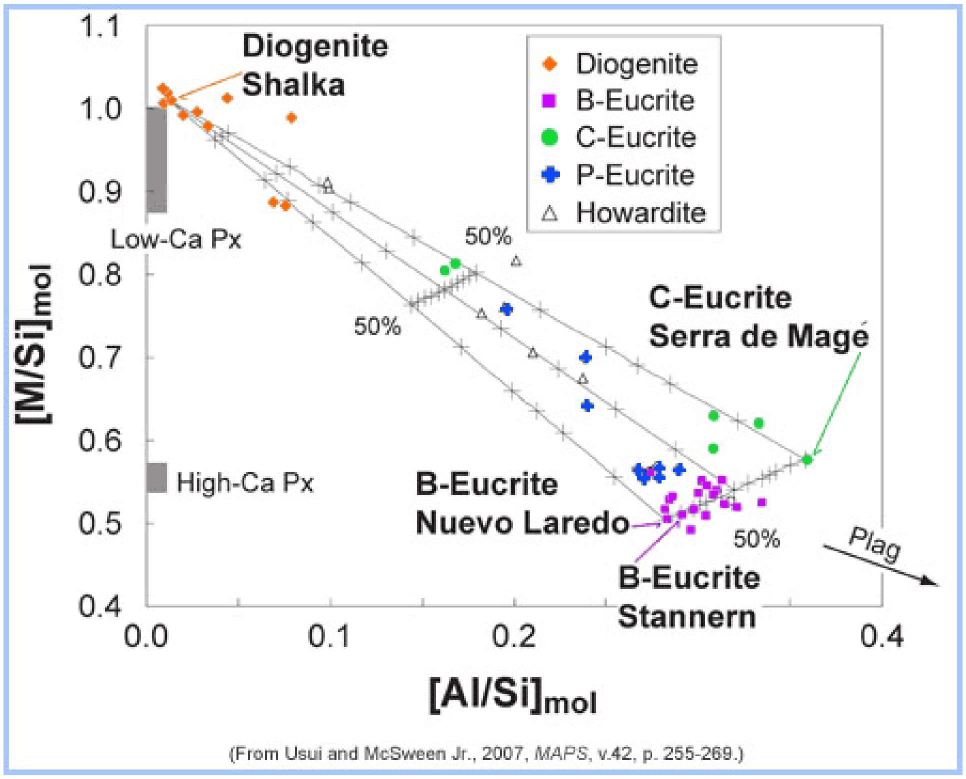
Mixing Model

Usui and McSween developed a way to evaluate the contribution of different HED rock types --diogenites, basaltic eucrites, and cumulate eucrites-- to the GRaND spectra. The table below provides microscope images, at the same scale, taken in cross-polarized light of thin-sections of these rock types. Each image links to additional information from the Meteoritical Bulletin Database maintained by the Meteoritical Society.

 (Courtesy of Sasha Krot, University of Hawaii.)	 (Courtesy of Sasha Krot, University of Hawaii.)	 (Courtesy of Sasha Krot, University of Hawaii.)
Type: Diogenite ***Name:*** Johnstown ***Source:*** Observed fall in United States, 1924. ***Description:*** Johnstown is a typical diogenite (cumulate rock formed at depth) composed almost entirely of coarse-grained orthopyroxene.	***Type:*** Basaltic Eucrite ***Name:*** Pasamonte ***Source:*** Observed fall in United States, 1933. ***Description:*** Pasamonte is a basaltic eucrite. Its fine-grained texture indicates the rock cooled quickly on the surface. The needle-shaped minerals are plagioclase. The larger crystals are pyroxene.	***Type:*** Cumulate Eucrite ***Name:*** Serra de Magé ***Source:*** Observed fall in Brazil, 1923. ***Description:*** Serra de Magé is a cumulate eucrite consisting almost entirely of pyroxene, which changed into a mixture of two different compositions as the rock cooled. You can see this as colored needles within the grey pyroxene grains. The other crystals in this image are plagioclase.

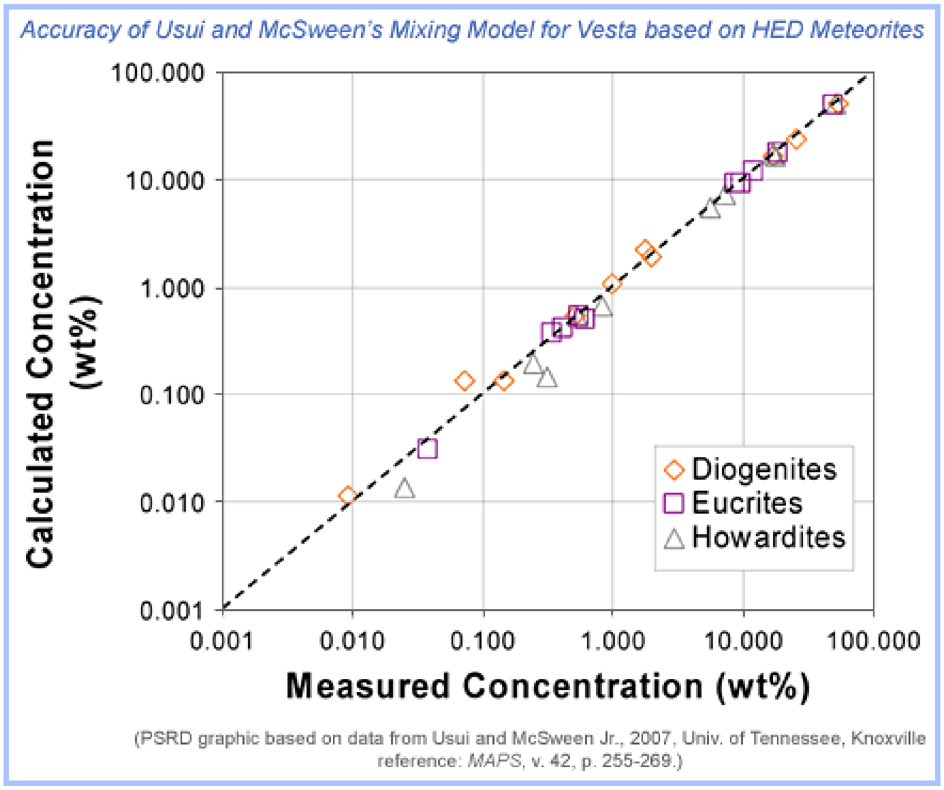
The research team decided to start with two mixing models using a diogenite named Shalka, the cumulate eucrite named Serra de Magé, and either one of two different basaltic ecurites named Stannern or Nuevo Laredo. Stannern and Nuevo Laredo, though basaltic ecurites, plot separately on graphs of Mg# (Mg/(Mg+Fe) ratio) versus TiO_2 which leads cosmochemists to think these rocks formed in different ways. One simple explanation (there are others) is Stannern formed by the primary, partial melting of the interior of Vesta, and Nuevo Laredo by fractional crystallization of a cooling magma body. They expect the chemical compositions on the surface of Vesta to be mixtures of the components of these rocks.

An interesting aspect of this approach is that the mixing relations of the three end-member rock types can be plotted in an appropriate two-dimensional diagram. The mixing model devised by Usui and McSween is based on molar ratios of the elements, magnesium, iron, aluminum, and silicon. They plot (Mg+Fe)/Si abbreviated as $[M/Si]_{mol}$ and Al/Si abbreviated as $[Al/Si]_{mol}$. This plot, below, shows how the three rock types are well discriminated compositionally. Diogenites are plotted in orange, cumulate eucrites in green, and basaltic eucrites in purple.



Graph showing the compositional differences between HED meteorites based on molar ratios of magnesium, iron, aluminum, and silicon. Arrows point to the specific data points for Shalka, Serra de Magé, Nuevo Laredo, and Stannern. Also plotted are polymict eucrites (labeled P-Eucrite) and Howardites, which are rocks that are breccias or mixtures of eucrite and diogenite fragments.

The graph, above, helps to show that the end member rocks define a space wherein all the HEDs plot. Using the three end members, Usui and McSween delineated mixing lines in the plot to create a mixing model for the upcoming GRaND data. Next, to show the accuracy of their model, Usui and McSween compared their modeled compositions with the actual, mean compositions for the meteorites based on concentrations of oxides of Si, Fe, Ti, Mg, Al, Ca, Cr, Mn, Na, and K. The next plot shows the excellent agreement between these compositions. The mixing model can accurately estimate the abundances of all the major elements that can be measured by GRaND as well as predict abundances of minor elements (Na, Cr, and Mn) not analyzed by the instrument.



This is a plot of the concentrations of oxides of Si, Fe, Ti, Mg, Al, Ca, Cr, Mn, Na, and K measured in HED meteorites versus their concentrations calculated from the mixing model developed by Usui and McSween. The dashed line represents perfect agreement between the two. In general the agreement is excellent. The diagram is plotted on a logarithmic scale to easily show all the elements on one diagram (K is lowest and Si is highest). Elements are not labeled to avoid cluttering the diagram.

If Vesta's surface chemistry is analogous to HED meteorites as expected, then the Usui and McSween HED-based mixing model will help determine the proportion of different rock types represented in the GRaND spectral data. The researchers say combining GRaND data with topographic data would yield further information on stratigraphic chemical variations. For example, finding evidence for the mineral olivine in the huge impact crater (460-kilimeters diameter) near Vesta's south pole would give information about the asteroid's mantle. Knowing this, Usui and McSween created another mixing model to show that it is possible to estimate the abundance of olivine from elemental data obtained by GRaND. Data from the visible and infrared mapping spectrometer onboard the Dawn spacecraft will further help to interpret the mineralogy on Vesta. As Usui and McSween point out, the new orbital data could help constrain the geological context for HED meteorites and provide new insight into the geologic history of the asteroid. If GRaND sends back spectra that do not mimic HED rock compositions, then that could mean we are seeing a rock type on the asteroid that is not yet in our meteorite collections.

No matter what, new cosmochemical data will help us get to know Vesta better. The use of the vast amount of data on HED meteorites to devise a mixing model to understand data from a spacecraft orbiting Vesta shows the value of an integrated approach to solar system exploration. Both laboratory analysis of samples like that funded by the Cosmochemistry Program and remote sensing data like that to be radioed back by the Dawn mission are crucial bits of information about the igneous histories of the building blocks of the planets.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- **PSRDpresents:** Getting to Know Vesta --Short Slide Summary (with accompanying notes).

- Dawn Mission homepage
- Keil, K. (2002) Geological History of Asteroid 4 Vesta: The Smallest Terrestrial Planet. In *Asteroids III*, (eds. W. F. Bottke, Jr., A. Cellino, P. Paolicchi, and R. P. Binzel.) University of Arizona Press, Tucson, AZ, p. 573-589.
- Krot, A. N., Keil, K., Scott, E. R. D., Goodrich, C. A., and Weisberg, M. K. (2007) Classification of Meteorites.

In *Treatise on Geochemistry, v. 1.05* (eds. H. D. Holland and K. K. Turekian.) Elsevier Ltd., 52 p.
- Prettyman, T. H. and 16 others (2006) Gamma Ray and Neutron Spectrometer for Dawn. 37th Lunar and Planetary Science Conference abstract 2231.
- Treiman, A. H., Lanzirotti, A., Xirouchakis, D. (2004) Ancient Water on Asteroid 4 Vesta: Evidence from a Quarz Veinlet in the Serra de Magé Eucrite Meteorite. *Earth and Planetary Science Letters*, v. 219, p. 189-199.
- Usui, T. and McSween, Jr., H. Y. (2007) Geochemistry of 4 Vesta based on HED meteorites: Prospective study for interpretation of gamma ray and neutron spectra for the Dawn mission. *Meteoritics and Planetary Science*, v. 41, p. 255-269.
- Vernazza, P., Mothé -Diniz, T., Barucci, M. A., Birlan, M., Carvano, J. M., Strazzulla, G., Fulchignoni, M., and Migliorini, A. (2005) Analysis of near-IR spectra of 1 Ceres and 4 Vesta, targets of the Dawn Mission. *Astronomy and Astrophysics*, v. 436, p. 1113-1121.

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