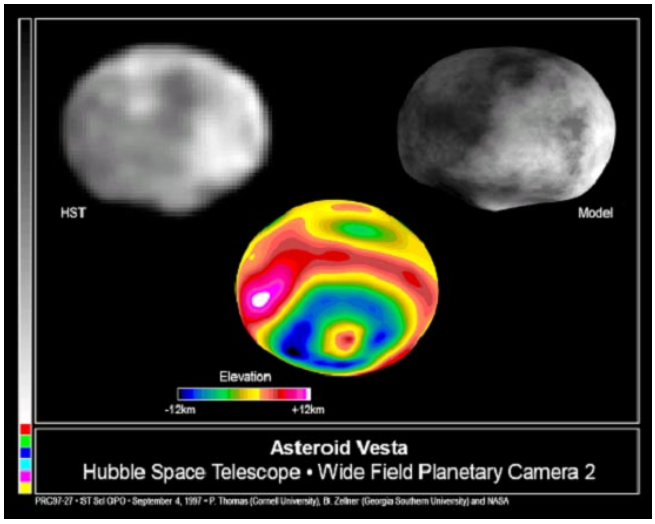
The Impact History of Asteroid 4-Vesta

Donald Bogard, Johnson Space Center

Eucrite meteorites are igneous rocks that derive from a large asteroid, probably 4-Vesta. Previous studies have shown that after eucrites formed approximately 4.56 Gyr (giga-years) ago, most subsequently metamorphosed to temperatures up to ~800° C and, much later, many were brecciated and heated by large impacts into the parent body surface. The less common basaltic, unbrecciated eucrites also formed near the surface, but presumably escaped later brecciation, whereas the cumulate eucrites formed at a depth where metamorphism may have persisted for a considerable period.

To further understand the complex HED parent body thermal history, we measured ^{39}Ar-^{40}Ar ages for nine eucrites classified as basaltic but unbrecciated, six eucrites classified as cumulate, and several basaltic-brecciated eucrites. The ^{39}Ar-^{40}Ar method is a variant of K-Ar dating, and is sensitive to moderate thermal events, including heating produced during impacts into surfaces. Precise Ar-Ar ages of two cumulate eucrites and four unbrecciated eucrites give a tight age cluster at 4.48 ±0.02 Gyr. Ar-Ar ages of six additional unbrecciated eucrites are consistent with this age, within their relatively larger age uncertainties.

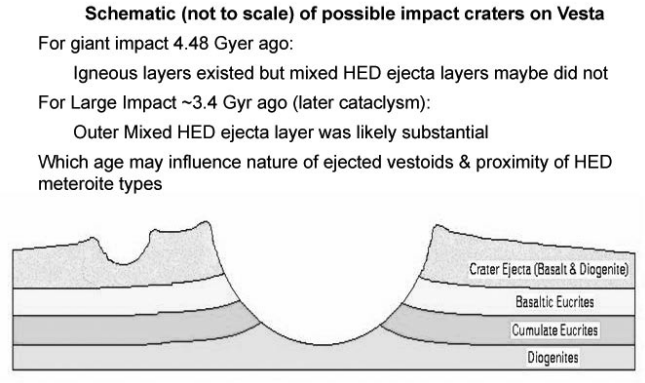


Asteroid Vesta.

In contrast, available literature data on Pb-Pb isochron ages of four cumulate eucrites and one unbrecciated eucrite vary over 4.4-4.515 Gyr, and ^{147}Sm-^{143}Nd isochron ages of four cumulate and three unbrecciated eucrites vary over 4.41-4.55 Gyr. Similar Ar-Ar ages for cumulate and unbrecciated eucrites imply that cumulate eucrites do not have a younger formation age than basaltic eucrites, as previously proposed. Rather, we suggest that these cumulate and unbrecciated eucrites resided at depth in their parent body (presumably Vesta), where temperatures were sufficiently high to cause the K-Ar and some other chronometers to remain open diffusion systems. From the strong clustering of Ar-Ar ages at ~4.48 Gyr, we propose that these meteorites were excavated from depth in a single large impact event ~4.48 Gyr ago, which quickly cooled the samples and started the K-Ar chronometer. A very large (~460 km diameter) crater observed on Vesta may be the source of these eucrites and of many smaller asteroids, called vestoids, thought to be spectrally or physically associated with Vesta. Some Pb-Pb and Sm-Nd ages of cumulate and unbrecciated eucrites are consistent with the 4.48 Gyr Ar-Ar age, and the few older Pb-Pb and Sm-Nd ages may reflect isotopic closure prior to the large cratering event.

Most basaltic eucrites are breccias formed by repeated impacts, and these typically show impact-reset Ar-Ar ages in the range of 3.4-3.7 Gyr. New Ar-Ar analyses of three cumulate eucrites and several basaltic eucrites give Ar-Ar ages consistent with this age range. We attribute all these younger ages to impact heating that occurred in an enhanced or cataclysmic bombardment of the inner solar system over the period of ~4.0-3.4 Gyr ago. An impact cataclysm has been proposed to have occurred on the

moon ~4.0-3.8 Gyr ago. The onset of major impact heating may have occurred at similar times for both Vesta and the moon, but impact heating appears to have persisted to a somewhat later time on Vesta when compared to the moon. Age dating of eucrites and lunar highland rocks currently offers the only method to characterize this impact cataclysm, which not only strongly influenced the early crustal development of all the inner planets, but also may have influenced the development of life on Earth.



Schematic (not to scale) of possible impact craters on Vesta.

We also used the Ar isotopic data obtained in age dating these eucrites to calculate their cosmic-ray, or space exposure, ages. These CRE ages are calculated from Ar that forms because of nuclear reactions produced from high-energy cosmic ray irradiation of objects in space. The CRE ages of eucrites range over ~4-50 mega-years (Myr) and measure the time that elapsed between meteorite ejection by impact from a parent body and their arrival on Earth. Because Vesta is located in an orbit that makes it difficult to eject meteorites directly to Earth, and because smaller asteroids, called vestoids, are located in dynamically more favorable orbits and are spectrally very similar to Vesta, vestoids are believed to be the direct parent bodies of eucrites. We suggest that vestoids were ejected from Vesta by the early Ar-Ar dated impacts, perhaps 3.4 Gyr ago. Eucrites are related to several other meteorite types, which collectively comprise a meteorite suite called HEDs that formed at different depths of ~0-20 km inVesta. About one-third of HEDs possesses a common CRE age of ~21 Myr. This implies that the immediate vestoid parent of HEDs contains all HED meteorite types, which were sampled by the ~21 Myr impact event, which itself must have been of significant size.

The NASA Discovery Program is developing a robotic mission called DAWN that will orbit Vesta and determine several of its characteristics.