

Dating the moon-forming impact event with meteorites

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This image shows a meteorite fragment found after a 17-20 meter asteroid disrupted in the atmosphere near Chelyabinsk, Russia on Feb. 15, 2013. The



blast wave produced by this event not only caused damage over a wide area but also created a strewn field of stony meteorites like this one. The meteorite is an ordinary chondrite (type LL5). It shows a beautiful contact between impact melt (dark material at top of image) and chondritic host (light material at bottom of image). Chondrules (circular features) are visible in the chondritic host at the bottom and right-hand side of the image. Portions of the chondrite were broken or otherwise separated and have migrated into the impact melt. The impact melt is estimated to be 4452±21 (Popova et al. 2013) and 4456±18 million years old (Lapen et al. 2014). These ages match the ~4470 million year old age of the Moon predicted by our model. We argue these impact melts were likely created when high velocity debris from the Moon-forming impact hit the parent asteroid of the Chelyabinsk bolide and heated near-surface material. Credit: Vishnu Reddy, Planetary Science Institute

Through a combination of data analysis and numerical modeling work, researchers have found a record of the ancient Moon-forming giant impact observable in stony meteorites. Their work will appear in the April 2015 issue of the Journal *Science*. The work was done by NASA Solar System Exploration Research Virtual Institute (SSERVI) researchers led by Principal Investigator Bill Bottke of the Institute for the Science of Exploration Targets (ISET) team at the Southwest Research Institute and included Tim Swindle, director of the University of Arizona's Lunar and Planetary Laboratory.

The inner Solar System's biggest known collision was the Moon-forming giant impact between a large protoplanet and the proto-Earth. The timing of this giant impact, however, is uncertain, with the ages of the most ancient lunar samples returned by the Apollo astronauts still being debated. Numerical simulations of the giant impact indicate this event not only created a disk of debris near Earth that formed the Moon, but it also ejected huge amounts of debris completely out of the Earth-Moon system. The fate of this material, comprising as much as several percent



of an Earth mass, has not been closely examined until recently. However, it is likely some of it blasted main belt asteroids, with a record plausibly left behind in their near-surface rocks. Collisions on these asteroids in more recent times delivered these shocked remnants to Earth, which scientists have now used to date the age of the Moon.

The research indicates numerous kilometer-sized fragments from the giant impact struck main belt asteroids at much higher velocities than typical main belt collisions, heating the surface and leaving behind a permanent record of the impact event. Evidence that the giant impact produced a large number of kilometer-sized fragments can be inferred from laboratory and numerical impact experiments, the ancient lunar impact record itself, and the numbers and sizes of fragments produced by major main belt asteroid collisions.

Once the team concluded that pieces of the Moon-forming impact hit main belt asteroids and left a record of shock heating events in some meteorites, they set out to deduce both the timing and the relative magnitude of the bombardment. By modeling the evolution of giant impact debris over time and fitting the results to ancient impact heat signatures in stony meteorites, the team was able to infer the Moon formed about 4.47 billion years ago, in agreement with many previous estimates. The most ancient Solar System materials found in meteorites are about one hundred million years older than this age.





This image shows the exterior of a meteorite produced when a small asteroid broke up in the atmosphere near Novato, California on Oct. 17, 2012. It shows extensive dark impact melt that is 4472±31 million years old (Yin et al. 2014). This age is similar to the ~4470 million year old age of the Moon predicted by our model. The Novato meteorite is classified as an ordinary chondrite (type L6). It came from a different asteroid than the Chelyabinsk bolide, but both experienced major impacts at roughly the same time as the Moon-forming giant impact. We argue these impact melts were created when high velocity debris from the Moon-forming impact event hit the parent asteroids of the Chelyabinsk and Novato bolides and heated near-surface material. Credit: Peter Jenniskens, SETI Institute



Insights into the last stages of planet formation in the <u>inner solar system</u> can be gleaned from these impact signatures. For example, the team is exploring how they can be used to place new constraints on how many asteroid-like bodies still existed in the inner Solar System in the aftermath of planet formation. They can also help researchers deduce the earliest bombardment history of ancient bodies like Vesta, one of the targets of NASA's Dawn mission and a main belt asteroid whose fragments were delivered to Earth in the form of meteorites. It is even possible that tiny remnants of the Moon-forming impactor or proto-Earth might still be found within meteorites that show signs of shock heating by giant impact debris. This would allow scientists to explore for the first time the unknown primordial nature of our homeworld.

Co-author Swindle, who specializes in finding the times when meteorites or lunar samples were involved in large collisions, said: "Bill Bottke had the idea of looking at the asteroid belt to see what effect a Moonforming giant impact would have, and realized that you would expect a lot of collisions in the period shortly after that.

"Here at LPL, we had been determining ages of impact events that affected meteorites, and when we got together, we found that our data matched his predictions," he added. "It's a great example of taking advantage of groups that work in two different specialties - orbital dynamics and chronology - and combining their expertise."

Intriguingly, some debris may have also returned to hit the Earth and Moon after remaining in solar orbit over timescales ranging from tens of thousands of years to 400 million years.

"The importance of giant impact ejecta returning to strike the Moon could also play an intriguing role in the earliest phase of lunar bombardment," said Bottke, who is an alumnus of the University of Arizona's Lunar and Planetary Laboratory. "This research is helping to



refine our time scales for 'what happened when' on other worlds in the Solar System."

Yvonne Pendleton, Director of the NASA SSERVI Institute, notes: "This is an excellent example of the power of multidisciplinary science. By linking studies of the Moon, of main belt asteroids, and of meteorites that fall to Earth, we gain a better understanding of the earliest history of our Solar System."

More information: "Dating the Moon-forming impact event with asteroidal meteorites," *Science*. <u>www.sciencemag.org/lookup/doi/ ...</u> <u>1126/science.aaa0602</u>

Provided by University of Arizona

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