How diamonds embedded in meteorites could offer a glimpse into the mantle of Mars

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On October 7, 2008, a 13-foot-long asteroid burst through Earth’s atmosphere and exploded above Sudan’s Nubian Desert. Its arrival created a stir because it was the first time that an asteroid that had been tracked and studied in space had collided with our planet. Even more intriguing, the bulk of the fragments that landed on Earth, collectively referred to as Almahata Sitta—the Arabic name of the train station near their landing site—turned out to be carbon-rich meteorites containing graphite and diamonds.

Such meteorites are called ureilites, and they usually contain tiny diamonds about 100 to 1,000 nanometers long. But a few of the Almahata Sitta meteorites had diamonds up to 100 times larger (1). “It was kind of an unusual sample,” says Meenakshi Wadhwa, director of the Center for Meteorite Studies at Arizona State University (ASU) in Tempe.

It was thought that diamonds in ureilites formed when a massive asteroid collided with a planet, with the planet destroyed in the collision. The ensuing high temperatures and pressures would have turned the asteroid’s graphite into diamond. But a new theory suggests that the Almahata Sitta ureilites may have come from material ejected from Mars when it was barely a few million years old. If so, the meteorites and the diamonds in them could be giving us our

As it descended to Earth, the asteroid known as 2008 TC3 left this contrail, captured by a cellphone camera. The asteroid’s scattered fragments and their composition have been the subject of intense study. Image credit: Mohamed Elhassan Abdelatif Mahir (Noub NGO), Dr. Muawia H. Shaddad (Univ. Khartoum), and Dr. Peter Jenniskens (SETI Institute/NASA Ames).
Researchers carefully sliced sections of one of the meteorite fragments found in Sudan’s Nubian Desert, revealing intriguing evidence that some of the diamond material inside eventually morphed into graphite. Image credit: Peter Jenniskens (SETI Institute).

first glimpse of the interior of another planet besides Earth.

Diamond Dilemmas
The Almahata Sitta diamonds pose many puzzles. First, they are so large that scientists have recently begun to question if even asteroid collisions were powerful enough to birth them. Also, although the diamonds themselves are surrounded by graphite, researchers aren’t in agreement as to whether the graphite came first and some of it was pressurized into diamonds or the diamonds came first and some of them disintegrated into graphite.

To find out, Farhang Nabiei, a researcher at the École Polytechnique Fédérale in Lausanne, Switzerland, examined the nitrogen isotopes within a sample of an Almahata Sitta meteorite and found material that is unstable at low pressures (2). Following up on previous work, Nabiei and his colleagues then carefully sliced sections of the meteorite and found evidence that some of the diamond material eventually morphed into graphite, a process that also requires at least 20 Gigapascals of pressure—the kind that can only be found inside a planet. That may sound counterintuitive, but diamond is metastable, and the shock of impact can change it back into graphite.

Nabiei’s results, published early this year, suggest that the original ureilite parent body was a planetary embryo the size of Mercury or Mars (2). The violent young solar system contained many such objects that collided with one another. In fact, our moon formed from ejecta created by a Mars-sized object slamming into Earth. A similar collision could have formed the ureilies.

Steve Desch, a planetary scientist at ASU, agrees with at least parts of the hypothesis. “The most unusual thing about ureilies is that its parent body was catastrophically disrupted,” he said at the annual meeting of the American Astronomical Society’s Division for Planetary Sciences in Knoxville, TN, last October. But although the impactor disrupted the ureilite parent body, it may have left some embedded shrapnel. Desch thinks he sees signs of this, and he argues it is from Mars.

According to Desch, the meteorites themselves reveal that the asteroid involved in their formation was only partially melted, and thermal models suggest it was small, only about 100 to 250 kilometers across, and would not have had the pressures needed to create diamonds. One source of the requisite pressure could have come from deep inside a planet, with a collision ejecting planetary debris into the asteroid belt. In search of a planet near the asteroid belt that suffered a massive collision in its past, Desch turned his eyes to Mars.

From Inside the Red Planet
There’s circumstantial evidence to suspect Mars was involved. In its northern hemisphere, the Red Planet contains a large depression called Borealis Basin that covers almost 40% of the planet’s surface. Some think the feature formed when a large body, between 1,600 and 2,700 kilometers wide, crashed into Mars about 4.5 billion years ago. Previous work by Ryuki Hyodo and Hidenori Genda (3), both of the Tokyo Institute of Technology in Tokyo, Japan, suggests that material ejected from such an impact can be hurled across the solar system. Some of it could have coagulated to form the Martian moons Phobos and Deimos, whereas some could have been flung farther out. And not all of the material would come from the planet’s surface. Because such a collision would have happened early in the life of the 4.7-billion-year-old solar system, before the planet’s mantle had crystallized, it could have ejected some mantle material too.

“The Borealis Basin-forming impact would excavate the Martian mantle material . . . into space, and it could finally mix with the asteroid belt,” Hyodo says.

Building on Hyodo’s work, Desch proposed that a giant slab of material carved from the Martian crust and mantle could have then slammed into an asteroid about 175 kilometers wide. According to Desch’s models, the fast-moving debris would have caused the catastrophic destruction of a primordial asteroid; Desch speculated the collision could have birthed the ureilite source. As the Martian debris and asteroid mixed together, they would have coalesced to form a collection of objects with the makeup of both. The resulting asteroids could contain small diamonds created by the shock of impact as well as large diamonds scooped out of the Martian mantle—the best of both worlds.

But Desch’s proposal requires an early Martian mantle full of diamonds. We know that Earth’s mantle is filled with diamonds—recent estimates pack a quadrillion tons into our planet’s interior. Whether or not diamonds could thrive in a Martian mantle is less well studied. By modeling the red planet’s formation, Desch’s research revealed that a process similar to what happened inside Earth could have produced diamonds on Mars, with a magma ocean covering the planet for a few million years.
Studies of other, non-ureilite meteorites have already suggested the possibility of a carbon-rich and graphite-rich Martian mantle, providing the ingredients for diamonds to form. As heavier elements such as iron sunk toward the center to form the core, the buoyant diamonds would have floated to the top of the magma ocean. Lower temperatures and pressures would convert the rising diamonds into graphite, creating what Desch calls “a substantial graphite layer” across the top of the planet’s mantle. Lying about 10 kilometers beneath the churning Martian surface, the graphite would lock up about half of the red planet’s carbon, which would explain observed differences in the isotopes of Martian meteorites from the crust and ureilite material ripped from the mantle.

On Earth, diamonds can contain material from the planet’s mantle that can reveal information about where they formed. Martian diamonds would do the same. Nabiei’s team found material inside the larger Almahata Sitta diamonds. “We had a big piece of diamond crystal, and we just smashed it, cracked it into fragments,” Nabiei says. They found chromite, phosphate, and iron-rich sulfides inside, suggesting that the diamonds formed without interacting with the silicates found on the surface of terrestrial planets. If ureilites contain pieces of the Martian mantle, “that would be a pretty big deal,” says Wadhwa. “It would be incredible to have something from the interior of a largish planet.” So far, Earth is the only world whose mantle samples have been collected, either in diamonds or molten mantle escaping volcanoes. Martian mantle samples could help researchers learn more about how the red planet formed.

But the idea that ureilites contain pieces of the Martian mantle requires a series of assumptions, warns Wadhwa. The Martian mantle must contain a graphite layer, and an impact must have created the Borealis Basin early enough to scoop out some of the diamond-rich material before it all converted to graphite. Debris from Mars had to collide with an existing object in the asteroid belt large enough to allow the pair to meld into one. And some of that material had to make its way to Earth. However, Wadhwa says that the assumptions are all reasonable. “To some extent, it does make sense to me,” she says.

**Misgivings About Mars**

Not everyone is convinced. Mars expert Marc Fries, a planetary scientist at NASA’s Johnson Space Center in Houston, TX, has a hard time accepting a layer of graphite in the Martian mantle. Based on observations of the surface, “Mars is one of the most carbon-depleted objects in the solar system,” he says, adding that the reason for the planet’s lack of visible carbon is an ongoing mystery. He also points out that the isotope measurements of Martian material and ureilites are “worlds apart.” Altogether, “I don’t think a Martian origin for the formation of ureilites is a plausible explanation,” he says.

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Nabiei isn’t sold on the idea either. “I don’t see how [ureilites] could be really linked to Mars,” he says. “It seems a bit far-fetched.” Like Fries, he’s concerned about the mismatch between the isotopes found in known Martian material and the meteorites.

NASA’s newest Mars Lander, InSight, might provide hints about whether a graphite layer exists there, but Desch says the clues won’t be conclusive. “InSight probably won’t test our theory, but we’re working toward the things the successors to InSight will measure,” he says. Understanding what future rovers turn up will require further study of the ureilites and the tiny time capsules they hold inside, whose contents rovers would be capable of inspecting.

In the meantime, Desch remains optimistic. He sees his model as an application of Occam’s razor—it’s simpler to invoke an existing planet, i.e., Mars, than one that was destroyed long ago. “We think we’ve made a good match to Mars,” he says. “I think that we got the whole thing.”

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