Earth's final growth spurt

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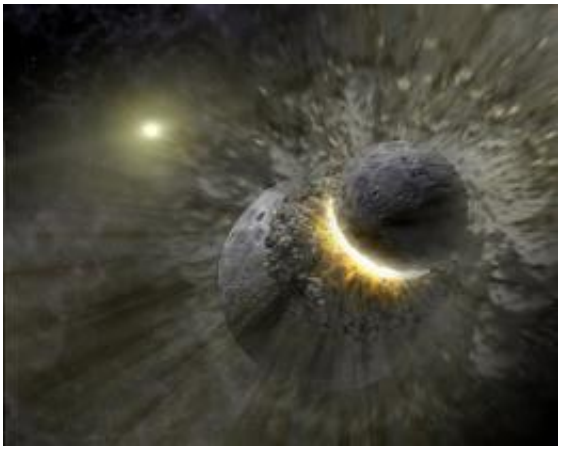

Massive planetesimals — some as large as 2,000 miles in diameter — may have struck other objects in space, including possibly Earth, Mars and the Moon, in a similar fashion to this artist's rendering of a space collision. Image: NASA/JPL-Caltech

What led to water on the interior of the Moon or the formation of the Borealis basin that covers 40 percent of the surface of Mars? And what caused at least some of Earth's tilt — without which there would be no change of seasons?

New research from NASA's Lunar Science Institute points to the same culprit: rocky bodies known as planetesimals that populated the solar system billions of years ago and eventually clumped together to form planets. As the planets and the Moon (which was created by a massive impact between a Mars-sized body and the young Earth) continued to

cool several hundred million years after their formation, planetary scientists believe that planetesimals struck them again.

Now scientists are one step closer to pinpointing the size of those rocky bodies that hit at the end of planet formation, a process known as accretion. Knowing this detail is important for understanding the evolution of Earth's surface and interior, and for understanding how Earth developed an environment that encouraged life. As Lindy Elkins-Tanton, the Mitsui Career Development Assistant Professor of Geology in MIT's Department of Earth, Atmospheric and Planetary Sciences, and researchers from the Southwest Research Institute (SwRI), the University of Maryland and Scripps Institution of Oceanography, suggest in a paper published last week in *Science*, the last bits of mass delivered by planetesimals to Earth, the Moon and Mars during the final stage of their formation did not consist of lots of tiny bodies, but rather, a handful of massive objects.

Based on computer modeling, lead author and SwRI planetary scientist William Bottke, Elkins-Tanton and their colleagues suggest that the largest planetesimal to strike Earth was between 1,500 and 2,000 miles wide (roughly the size of Pluto), the largest for Mars was 900 to 1,100 miles wide (about the distance from Seattle to Southern California) and those that hit the Moon were 150 to 200 miles in diameter (about the distance between Boston and New York).

Reconstructing planetesimals

The research may also help solve a longstanding conundrum. Many planetary scientists believe that the Moon formed about 4.5 billion years ago from a giant impact that is thought to have led to the final phase of differentiation on Earth — the process by which denser materials sank to Earth's interior to form a core and lighter materials formed the outer layers known as a mantle and crust. During this process, elements that

are attracted to dense, metallic elements like iron should have followed those metallic elements deep into Earth's interior. That means there should be no trace of highly siderophile, or metal-loving, elements in Earth's outer layers.

But rocks that have been brought to Earth's surface by volcanic activity, lunar samples collected during the Apollo missions and chunks of meteorites from Mars are chockfull of highly siderophile elements like gold and iridium. Elkins-Tanton and her colleagues wondered if late-arriving planetesimals were responsible for dumping rocks that contained siderophile elements onto Earth, the Moon and Mars. If so, the researchers estimate that the late-arriving planetesimals would have had to deliver at least 0.5 percent of Earth's mass to Earth's mantle, and about 10 to 1,200 times less mass to the Martian and lunar mantles, respectively.

After running thousands of computer simulations that considered a range of projectile sizes and distributions, the researchers show that it's possible that planetesimals were large enough to replenish highly siderophile elements to the mantles of Earth, the Moon and Mars. Those projectiles were also capable of modifying Earth's tilt by 10 degrees, creating basins on the Martian and lunar surfaces, and possibly delivering water to the Moon, according to the paper.

Confirmation from Mars

Richard Carlson, a researcher at the Carnegie Institution's Department of Terrestial Magnetism, says that the suggestion that massive planetesimals delivered siderophile elements "fits in reasonably well" with what scientists know about accretion. He thinks that samples taken directly from the Martian crust "would really be the confirming evidence" for the theory. That's because unlike Earth's crust, which has been erased through plate tectonics — the process by which rigid plates slowly shift

across the underlying mantle — the Martian crust hasn't changed much since it formed.

In future work, Elkins-Tanton hopes to explore more details about the delivery of water on the Moon, which remains a mystery because the water that has been measured in lunar rocks doesn't support what otherwise appears to be a very dry body, both inside and out.

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