Study zeros in on plate tectonics' start date

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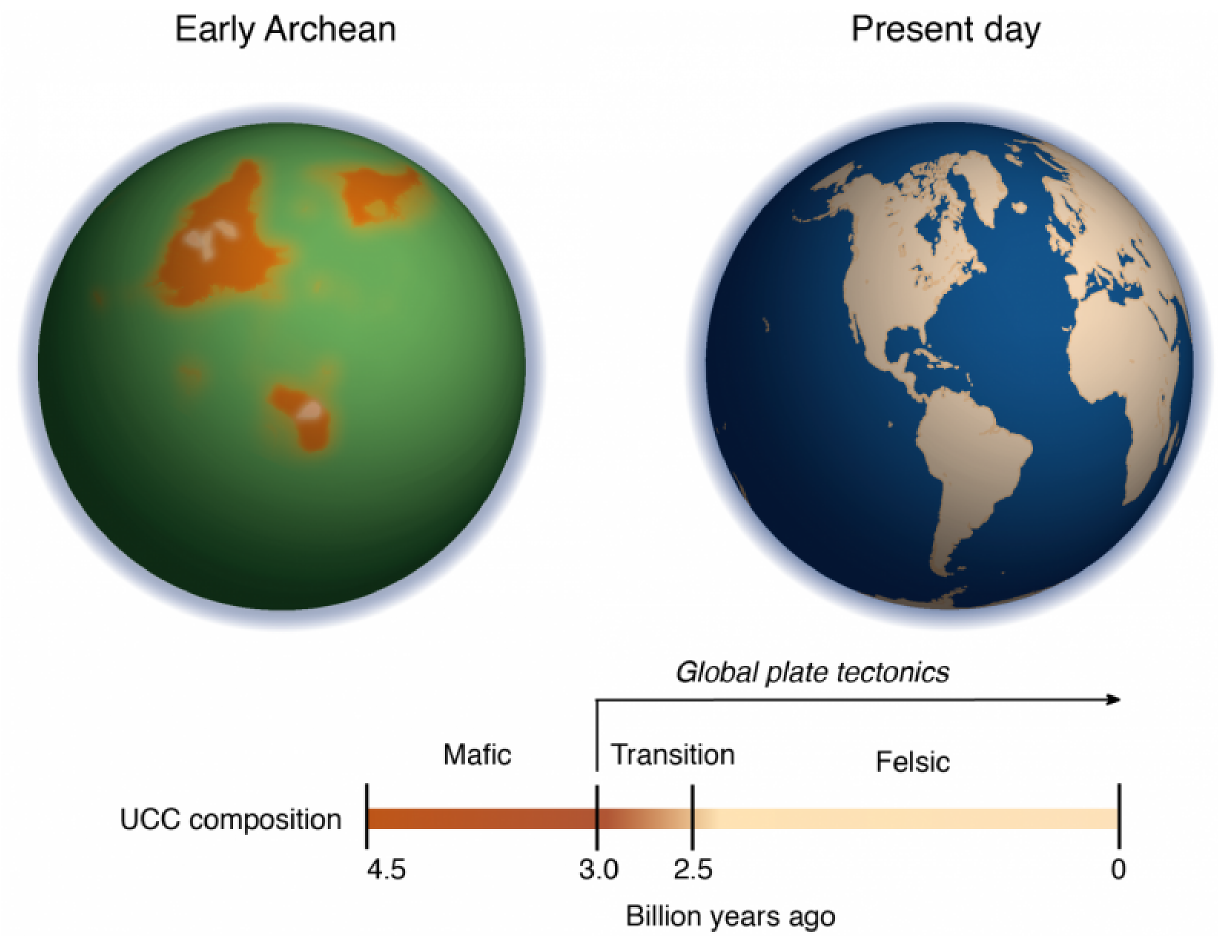

The image at left depicts what Earth might have looked like more than 3 billion years ago in the early Archean. The orange shapes represent the magnesium-rich proto-continents before plate tectonics started--although it is impossible to determine their precise shapes and locations. The ocean appears green due to a high amount of iron (Fe[II]) ions in the water at that time. The timeline traces the transition from a magnesium-rich (mafic) upper continental crust (UCC) to a magnesium-poor (felsic) UCC. Credit: Ming Tang/UMD

Earth has some special features that set it apart from its close cousins in the solar system, including large oceans of liquid water and a rich atmosphere with just the right ingredients to support life as we know it. Earth is also the only planet that has an active outer layer made of large tectonic plates that grind together and dip beneath each other, giving rise to mountains, volcanoes, earthquakes and large continents of land.

Geologists have long debated when these processes, collectively known as plate tectonics, first got underway. Some scientists propose that the process began as early as 4.5 billion years ago, shortly after Earth's formation. Others suggest a much more recent start within the last 800 million years. A study from the University of Maryland provides new geochemical evidence for a middle ground between these two extremes: An analysis of trace element ratios that correlate to magnesium content suggests that plate tectonics began about 3 billion years ago. The results appear in the January 22, 2016 issue of the journal *Science*.

"By linking crustal composition and plate tectonics, we have provided first-order geochemical evidence for the onset of plate tectonics, which is a fundamental Earth science question," said Ming Tang, a graduate student in geology at UMD and lead author of the study. "Because plate tectonics is necessary for the building of continents, this work also represents a further step in understanding when and how Earth's continents formed."

The study zeros in on one key characteristic of Earth's crust that sets it apart geochemically from other terrestrial planets in the solar system. Compared with Mars, Mercury, Venus and even our own moon, Earth's continental crust contains less magnesium. Early in its history, however, Earth's crust more closely resembled its cousins, with a higher proportion of magnesium.

At some point, Earth's crust evolved to contain more granite, a magnesium-poor rock that forms the basis of Earth's continents. Many geoscientists agree that the start of plate tectonics drove this transition by dragging water underneath the crust, which is a necessary step to make granite.

"You can't have continents without granite, and you can't have granite without taking water deep into the Earth," said Roberta Rudnick, former chair of the Department of Geology at UMD and senior author on the study. Rudnick, who is now a professor of earth sciences at the University of California, Santa Barbara, conducted this research while at UMD. "So at some point plate tectonics began and started bringing lots of water down into the mantle. The big question is when did that happen?"

A logical approach would be to look at the magnesium content in ancient rocks formed across a wide span of time, to determine when this transition toward low-magnesium crustal rocks began. However, this has proven difficult because the direct evidence—magnesium—has a pesky habit of washing away into the ocean once rocks are exposed to the surface.

Tang, Rudnick and Kang Chen, a graduate student at China University of Geosciences on a one and a half-year research visit to UMD, sidestepped this problem by looking at trace elements that are not soluble in water. These elements—nickel, cobalt, chromium and zinc—stay behind long after most of the magnesium has washed away. The researchers found that the ratios of these elements hold the key: higher ratios of nickel to cobalt and chromium to zinc both correlate to higher magnesium content in the original rock.

"To our knowledge, we are the first to discover this correlation and use this approach," Tang said. "Because the ratios of these trace elements correlate to magnesium, they serve as a very reliable 'fingerprint' of past magnesium content."

Tang and his coauthors compiled trace element data taken from a variety of ancient rocks that formed in the Archean eon, a time period between 4 and 2.5 billion years ago, and used it to determine the magnesium content in the rocks when they were first formed. They used these data to construct a computer model of the early Earth's geochemical composition. This model accounted for how magnesium (specifically, magnesium oxide) content in the crust changed over time.

The results suggest that 3 billion years ago, the Earth's crust had roughly 11 percent magnesium oxide by weight. Within a half billion years, that number had dropped to about 4 percent, which is very close to the 2 or 3 percent magnesium oxide seen in today's crust. This suggested that plate tectonics began about 3 billion years ago, giving rise to the continents we see today.

"It's really kind of a radical idea, to suggest that continental crust in Archean had that much magnesium," said Rudnick, pointing out that Tang was the first to work out the correlation between trace element ratios and magnesium. "Ming's discovery is powerful because he found that trace insoluble elements correlate with a major element, allowing us to address a long-standing question in Earth history."

"Because the evolution of continental crust is linked to many major geological processes on Earth, this work may provide a basis for a variety of future studies of Earth history," Tang said. "For example, weathering of this magnesium-rich crust may have affected the chemistry of the ancient ocean, where life on Earth evolved. As for the onset of plate tectonics, I don't think this study will close the argument, but it certainly adds a compelling new dimension to the discussion."

More information: "Archean upper crust transition from mafic to felsic marks the onset of plate tectonics" DOI: 10.1126/science.aad5513

Provided by University of Maryland

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