EarthDate

Ripples in Earth's Crust

Surface ripples and backjet that occur after an impact on a water surface are similar to features formed by the Chicxulub impactor, which caused Earth's surface to briefly behave like a fluid.

Previously, we talked about how scientists discovered the asteroid that brought down the dinosaurs.

But what exactly happened when a rock twice the size of Manhattan smashed into our planet—with the force of 10 *billion* atomic bombs?

It punched a hole in Earth's crust 50 miles wide and 20 miles deep, causing nearly a million cubic *miles* of solid rock to behave like liquid.

Like when a rock lands in a pond, the sides of the crater splashed outward, up, then collapsed. The center of the crater rebounded, rocketing up higher than Mount Everest; then it, too, collapsed.

Earth's crust rippled like the surface of water. A ring of ridges spread out from the impact site.

This giant "splash" on Earth's surface happened in a matter of minutes. Then, the rocks froze into their new positions and were protected from erosion by layers of marine sediment.

A 2016 mission drilled into the ridges circling the crater floor. The explorers found large sections of melted rock.

Below that, they found granites so badly pulverized that they were less dense than normal granite.

And, as often happens in science, one insight leads to another.

A recent space mission had discovered that the moon's crust is less dense than it should be, and scientists wondered why.

The crater on Earth suggests it's due to 4 billion years of impacts on the moon's famously cratered surface.

Bureau of Economic Geology

Background: Ripples in Earth's Crust

Synopsis: Sixty-six million years ago, a giant asteroid 7.5 mi (12 km) across crashed into ancient shallow seas, today covering the Yucatán Peninsula, with ten billion times the power of the Hiroshima nuclear bomb. Like water ripples created when a stone splashes into a pond, the impact rippled Earth's crust, resulting in a crater about 124 mi (200 km) wide that was preserved when millions of years of marine sediments buried it.

- Some definitions of heavenly bodies:
  - Comets are icy objects in space. Asteroids are rocky objects in space.
  - Meteors, also called "shooting stars," are icy or rocky objects in space that vaporize when they contact Earth's atmosphere.
  - A meteor that makes it through the atmosphere and hits Earth probably started as an asteroid but is called a meteorite upon impact. These can be iron meteorites made up of about 90 percent iron or stony meteorites that contain oxygen, iron, silica, magnesium, and other elements. Larger meteorites make impact craters.
- We can readily see thousands of craters on the moon and rocky planets, but we don't often see them on Earth because of erosion, burial, and crustal recycling by plate tectonics.
  - The structure of craters differs depending on their scale.
    - The smallest craters—like Barringer, or Meteor, Crater—look like bowls.
    - Slightly larger craters are bowls with a peak in the center.
    - Still larger craters have a ring of mountains circling the center peak ring.
    - The largest craters have a peak ring surrounded by multiple rings of faults.
  - On the dark side of the moon near the south lunar pole, the 200 mi (320 km) in diameter Schrödinger crater, which we can only view from lunar orbiters, is a peak-ring crater. Orientale, also on the moon, is more than 560 mi (900 km) in diameter and has multiple rings—the same area as the state of Texas.
  - Two of the three largest impact craters on Earth are deeply eroded: the 1.8-billion-year-old Sudbury crater in Canada and the 2.0-billion-year-old Vredefort crater in South Africa. The third is the buried, and thus preserved, 66-million-year-old Chicxulub crater in Mexico.
- Two prevailing hypotheses consider how peak rings in impact craters form, but no data existed to prove or disprove them—until 2016.
  - *Nested melt-cavity theory* suggests surface melting and side collapse to eventually produce the observed ring of mountains made from shallow material.
  - *Dynamic collapse theory* suggests that on impact, material propelled from deep in the mid-crust crests into an overheightened peak (possibly twice the height of Everest) that collapses into the peak ring—forming catastrophically in just minutes.
- The Chicxulub crater is the only preserved peak-ring crater that Earthlings can investigate.
  - Up to 3300 ft (1 km) of seabed sediments filled the underwater impact site for millions of years, protecting the rugged structure from erosion but also preventing us from being able to directly observe it.
  - Scientists use indirect methods like remote sensing and seismic imaging to map the crater's 3D configuration and to understand the distribution of properties like density and magnetic signature.
    - Scientists were surprised to find that the velocity of seismic waves travelling through rocks in the peak ring was slower than expected, meaning that the rocks were likely to be less dense than the melt rocks and deep crustal rocks predicted by the dynamic collapse theory.

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The Formation of Peak Rings in Large Impact Craters | Science
Drilling into Dino Doomsday | UT Austin Jackson School News
Asteroid Strike Made "Instant Himalayas" | BBC
New Simulation Supports Chicxulub Impact Scenario | Eos
At the "Crater of Doom," Geologists Dig Up Rocks from the Day the Dinosaurs Died | Washington Post

Contributors: Dr. Sean Gulick (UT Austin Institute for Geophysics), Juli Hennings, Harry Lynch

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- Researchers can also directly sample rocks in the crater by drilling boreholes into this feature, collecting cores just a few centimeters wide. For many years, they had gathered data and samples from a few scattered wells in the region but none from the peak ring.
  - Their models estimated that the 7.5-mi-wide (12-km-wide) meteorite was traveling westward at about 45,000 mph (20 km per second) when it struck a shallow, sloping coastal carbonate ramp at about 60°, creating a crater 124 mi (200 km) wide that fractured the crust to 20 mi (30 km) deep.
  - They estimate that the crater formed in less than 5 minutes, releasing ten billion times as much energy as the Hiroshima nuclear bomb—1023 joules, or the equivalent of about 24 million megatons of TNT.

Co-chiefs Joanna Morgan (left) and Sean Gulick examining core samples in labs on the *Liftboat Myrtle*.

Credit: UT Austin Jackson School of Geosciences

- In 2016, to determine the type of low-density rocks in the peak ring of Chicxulub, members of the International Ocean Discovery Program (IODP) Expedition 364 drilled to the peak ring from a three-legged drilling platform called the *Liftboat Myrtle* about 15 miles offshore of the Mexican town of Progreso.
  - They drilled a total of 4,380 ft (1,335 m) to directly sample the peak-ring rocks impacted by the meteorite and found a multicolored variety of rock types.
    - The rig stood in 50 ft (15 m) of water.
    - After drilling into the seafloor through 1,640 ft (500 m) of sediments, the scientists started coring and recovered 384 ft (117 m) of Eocene and Paleocene sediments. They found a sand deposit several meters thick that is interpreted to be a tsunami deposit, just above the impact rocks.
    - They then cored 426 ft (130 m) of impact breccia—rubble of many kinds of rocks, including melt rock. Then, 98 ft (30 m) of black melt rock.
    - Finally, they recovered 1,968 ft (600 m) of pink granite that makes up the peak ring, peppered with crosscutting dikes and faults. This material originated from about 6 mi (10 km) down in the mid-crust. The fact that it was not shallow material that had slumped into the crater proved that the dynamic collapse theory was correct.
  - The scientists found out that seismic velocities didn't lie! Rocks in the crater were indeed less dense than they should have been—the heavily fractured rocks had more than 10 percent porosity, down to the microscopic scale.
- When the Chicxulub meteorite slammed into the shallow seas at more than 45,000 mph (20 km per second), its force caused Earth's surface to momentarily lose strength and cohesion—it behaved like a viscous fluid, even though it remained a solid.
  - According to the data and detailed modeling, here's what took place in only 5–10 minutes:
    - A 7.5-mi (12-km) wide stony asteroid punched a cavity in Earth 18.5 mi (30 km) deep and 62 mi (100 km) wide, crushing the surface downward and forcing rocks outward.

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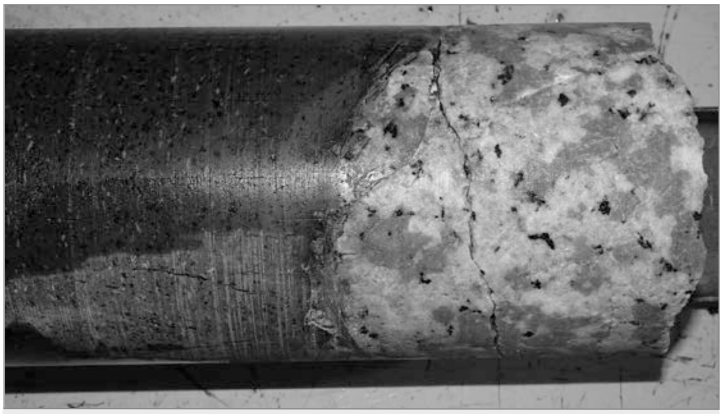
- The nearly vertical unsupported sides of the cavity started to collapse inward while the pulverized center of the bowl rebounded upward like a water backjet, possibly twice as high as Mount Everest.
- The column of rock then collapsed back downward, forcing rocks outward like a wave over the collapsed edges of the hole. Mid-crust material from 10 km deep landed on top of sediments that collapsed inward from the edge, creating the 1800-ft (550-m) tall peak-ring mountain range.
- Afterward, marine sediments filled in the bathymetry to preserve the structure. Without this burial, the evidence and structure of the impact would have eroded long ago.

- The peak ring of Chicxulub tells us about other craters in our universe.
    - Earth's surface is continually recycled by plate tectonics, driven by its dynamic interior, so the effects of most impacts are erased as plates are subducted.
    - The moon and other rocky planets in the Solar System don't have moving tectonic plates, but they are resurfaced by large impacts.
        - These events mix near-surface rocks with deeper material; modeling helps predict the original depth range of peak-ring materials.
        - Knowing the origin of these rocks provides a view to the crustal composition via remote sensing or using rovers in future space missions.
    - Knowing that these impacts also create porosity explains our recent observation that the moon's crust is entirely low density because it has been battered by impacts for 4.5 billion years.
        - This porosity could hold water circulating from hot, deep layers—hydrothermal systems—within the impact structures. On Earth, hydrothermal systems harbor unique subsurface ecosystems that are much different than surface ecosystems—these are important to think about in the search for habitability of other planets.
- We'll talk about what happened around the globe on the day of the impact, and about how life rebounded after the impact, in future episodes of EarthDate.



A core collected from peak ring of Chicxulub crater during IODP Expedition 364 showing impact melt rock (black) on top of uplifted granitoid rock from 10 km deep in crust. Granitoid displays both brittle and ductile deformation as a result of impact-generated shock wave and subsequent movement of these rocks. Orientation of tiny cracks in rocks caused by that shock and movement agrees with new model calculations of impact and its aftermath.

Credit: DSmith@ECORD

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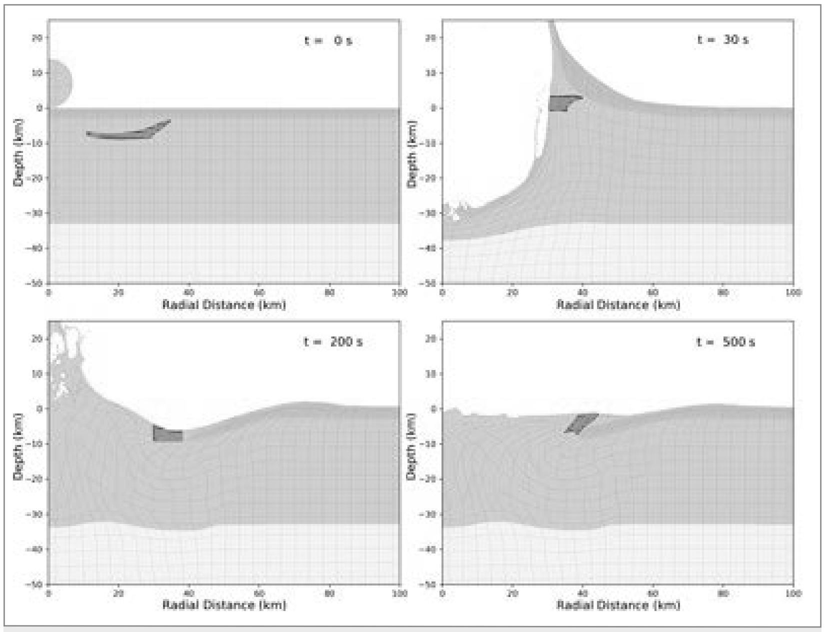

Four stages in formation of peak ring according to dynamic collapse model. Most rocks indicated in red start out more than 3 miles (5 km) below the surface (time t = 0 seconds). After impact creates a shock wave that pushes these rocks upward and to side (t = 30 seconds), the rocks slide down with the unstable sides of the "transient cavity" (t = 200 seconds) but eventually are lifted up with material rising from center (t = 500 seconds). Finally, these rocks are pushed over the original surface of sedimentary rocks.

Credit: A. Rae, Imperial College London

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