

The tsunami triggered by the Chicxulub impact

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The large wave caused by the dinosaur-killing asteroid impact eroded the seafloor and disturbed sediments in ocean basins far from the collision site.

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An asteroid struck the ocean's continental shelf near the modern-day Mexican town of Chicxulub some 66 million years ago. The collision energy was 3×10^{23} J, which is equivalent to about 5 billion Hiroshima-sized atomic bomb explosions. Within seconds, the impact excavated a hole more than 20 km deep into Earth's surface and threw bedrock and sediment into the upper atmosphere.

As impact ejecta fell back to Earth, the heat from their reentry generated a global pulse of thermal radiation similar to the conditions of an oven set on broil for about one hour. The thermal radiant flux and hot falling ejecta ignited widespread forest fires. The resulting soot blocked sunlight for several years, and the ensuing frigid surface temperatures led to widespread plant die-offs and the demise of a vast array of animals. Approximately 75% of species, most famously the non-avian dinosaurs, went extinct shortly after impact. Other life forms, including mammals and flowering plants, reemerged as dominant species.

Scientists in the 1980s and 1990s pinpointed the crater location from anomalies in Earth's gravity and magnetic fields. More recently, measurements from drill cores

corroborated the basic conclusions of crater-formation models. They also suggested that the impact could have triggered a powerful tsunami. Motivated by that possibility, the three of us and several colleagues asked whether such a tsunami could have had global effects. In 2022 we published the first global simulation of the Chicxulub megatsunami—the wave produced by the oceanic impact.

The first 10 minutes after the initial impact and the tsunami's formation were simulated with a shock-physics model that's widely used to study crater formation on Earth and other bodies in the solar system. The results of that model were then fed into propagation models to track the tsunami across the globe for two days. Finally, we examined geological records for evidence of global tsunami propagation.

Simulating the impact

The cavity formed by the impact was initially 28 km deep, but under the force of gravity, it collapsed into a crater roughly 3 km deep. As the crater took shape, a curtain of ejecta pushed water outward and initiated the advancing rim wave, shown in blue in figure 1. Some 10 minutes after impact, the wave had spread more than 200 km from the collision site, its width had grown to 50 km, and its height reached 1.5 km. The energy of the impact tsunami was about 30 000 times as great as that of any tsunami generated by a large earthquake today, including the 2004 Boxing Day tsunami that originated off the coast of Sumatra in the Indian Ocean (see *Physics Today*, June 2005, page 19) and the 2011 Tohoku tsunami generated near Japan (see the article by Thorne Lay and Hiroo Kanamori, *Physics Today*, December 2011, page 33).

Today's large tsunamis are simulated with shallow-water wave models, which assume that a tsunami's wavelength is much greater than the ocean depth. For the Chicxulub tsunami, the water in the nearby Gulf of Mexico deepens rapidly. The exact depth of the ocean 66 million years ago, however, is highly uncertain. But regardless

of what the water depth may have been then, the model's results were about the same for all simulations, in which the depths ranged from 1000 to 3000 m. The tsunami for each simulation evolved into a 100-km-long wave—enough to satisfy the shallow-water assumption—10 minutes after impact.

Figure 2 shows the size of the waves that coastlines across the globe may have seen from the tsunami. Modeled tsunami amplitudes were largest near the impact site in the Gulf of Mexico, where coastlines were hit with waves more than 100 m high. Large-amplitude waves also inundated ocean basins far from the impact. The tsunami traveled at about 200 m/s in the open ocean, and it circled the globe in about two days. During that time, the tsunami approached most coastlines with an amplitude of more than 1 m and hit many of them with an amplitude that exceeded 10 m. We expect that the Chicxulub megatsunami caused coastal flooding similar to that of the largest recorded tsunamis but on a global scale.

Because the Chicxulub impact took place 66 million years ago, Earth's continents and mid-ocean ridges were in different locations than they are today. To capture the tsunami's evolution, we used an ocean basin map with boundaries that were drawn by plate-tectonics experts. The land bridge between North America and South America, for example, was absent, so the propagating tsunami wave easily entered the Pacific Ocean.

Connecting the geological record

According to figure 2, the tsunami wave height was at its largest in the Gulf of Mexico and the North Atlantic and South Pacific Oceans. Open-ocean tsunami velocities were as large as 100 m/s in the Gulf of Mexico and the Caribbean Sea basins and smaller yet significant farther away from the impact site. Flows that are faster than 20 cm/s are capable of eroding sediment, and our modeled open-ocean tsunami velocities

exceeded that threshold in the North Atlantic and South Pacific as well as the Gulf of Mexico and Caribbean.

To assess how realistic the simulation results may be, we compared them with sedimentary records located throughout the globe on land and in the open ocean. Open-ocean sediment cores are obtained with ocean drilling vessels that use the same technologies as oil drilling rigs. The deeper one looks into a sedimentary record, the farther one travels back in time, and the individual layers of rock can be dated through measurements of radioactive isotopes.

Consistent with the tsunami model results, sediment cores from 66 million years ago suggest that erosion was substantial in the Gulf of Mexico, the Caribbean, the North Atlantic, and the South Pacific. Sediments appear to be less eroded where the tsunami model predicts weak velocities, including in the Mediterranean Sea and the South Atlantic and North Pacific ocean basins.

We are already working on a follow-up study in which we simulate the coastal flooding caused by the tsunami. We are using estimates of land elevations and revised representations of continental geometries **that take into account more geological constraints**, especially near the impact site and in selected far-field regions that experienced large tsunami wave heights and velocities. A new simulation that incorporates the detailed physics of coastal flooding should allow for a closer comparison between model results and geological records from the open ocean and coastal areas.

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Additional resources

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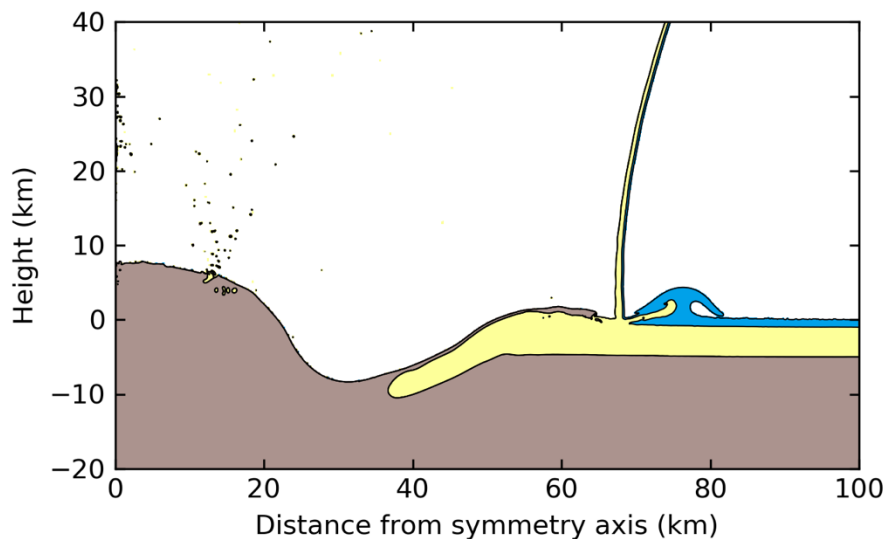


Figure 1. The Chicxulub impact 66 million years ago displaced crustal material (brown) and sediments (yellow) and launched a tsunami that spread around the globe. The origin marks the point of impact. A curtain of ejected sediment, tens of kilometers high, pushed ocean water outward to form a 4.5-km-high [Q: correct?] rim wave (blue), 4.5-km-high at 2.5 minutes after impact, that traversed Earth's oceans.

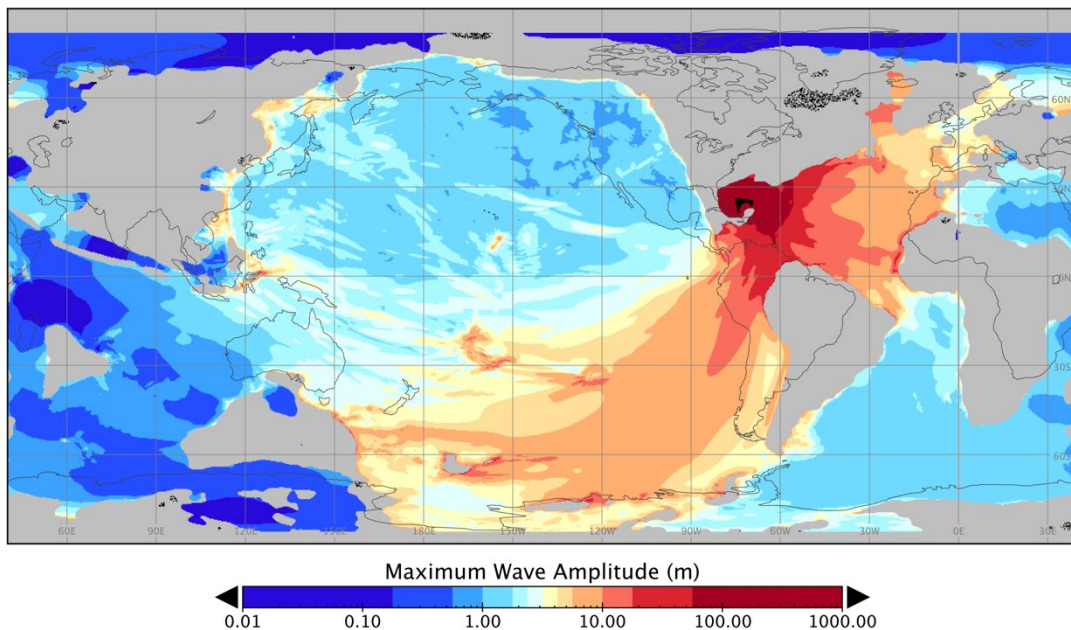


Figure 2. The wave created by the dinosaur-killing asteroid impact made its way to most of the world's oceans. Colors indicate the maximum amplitude of the Chicxulub tsunami around the locations of ancient continents (gray), with the location of today's continents outlined in black for reference. Open-ocean tsunami amplitudes were highest in the Gulf of Mexico, the Caribbean Sea, and the North Atlantic and South Pacific Oceans.