**We are now shooting at the stars.**

**Well, not stars, but asteroids.**

Before December, the National Aeronautics and Space Administration (NASA) will be shooting at an asteroid, to see if we can deflect the path of an asteroid. Why?

Recall that our Earth was struck by an asteroid millions of years ago, that affected our whole planet and resulted in initiating an ice age that eliminated most of life, including dinosaurs and plants. We don’t want that to happen again, as we already have enough problems with climate change, and an errant asteroid could really accelerate the changes that are disrupting life on our planet.

The target asteroid is not projected to threaten Earth, but we need to learn how to deflect a future asteroid we detect heading our way.

The project is managed for NASA by the Johns Hopkins University’s Applied Physics Laboratory in Laurel, Md. Our scientists John Hopkins are trying to be missile men in space. Let’s hope they are successful, or at least learn enough to be successful in the future.

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**NASA Planetary Defense Mission Aims to Push Distant Asteroid Off Its Path**

***Move will test technique that one day might avert an apocalyptic collision with Earth***

**By Robert Lee Hotz. *WSJ,* Nov. 23, 2021**

The first planetary defense mission takes to the skies early Wednesday, when the National Aeronautics and Space Administration launches a space probe designed to deflect a distant asteroid in a test of technology that might one day save the world.

The $324 million Double Asteroid Redirection Test, or DART, mission—a practice run for future efforts to protect Earth from collisions with asteroids and comets—is scheduled to launch aboard a SpaceX Falcon 9 rocket at 1:21 a.m. EST from Vandenberg Space Force Base in California. **Next fall, after a journey of more than six million miles, the probe will crash at 15,000 miles an hour into Dimorphos, a tiny moonlet that orbits a larger asteroid called Didymos.**

Mission planners expect the high-speed impact to alter the trajectory of the binary asteroid, which isn’t believed to pose a threat.

“For the first time, humanity will change the motion of a natural celestial body in space,” said DART program scientist Tom Statler of NASA. The project is managed for NASA by the Johns Hopkins University’s Applied Physics Laboratory in Laurel, Md.

‘For the first time, humanity will change the motion of a natural celestial body in space.’

— DART program scientist Tom Statler of NASA

Every day, Earth is showered with tons of cosmic debris, including chunks of ice, rock and iron that come at our planet like bricks from the junkyard of deep space. Most of these burn up harmlessly in the atmosphere, though spectacular exceptions to that rule have raised fears that a colossal space rock might one day be found to be on a collision course with Earth.

In 1908, for example, a mysterious space rock exploded over Siberia and leveled 830 square miles of forest. In 2013, a 65-foot asteroid blew apart 20 miles above Chelyabinsk, Russia. That airburst released more than 30 times the energy of the atomic bomb dropped on Hiroshima. It knocked people off their feet and blew out windows in thousands of buildigs.

At the urging of Congress, astronomers have identified and tracked the trajectories of about 1,000 asteroids about 3,300 feet across or larger that periodically come near Earth’s orbit. None of these mountain-size space rocks is believed to pose a threat to our planet for at least the next several centuries, though there’s a remote chance an undetected asteroid could damage the planet.

“While this is not something that is very likely to happen, it is not something we want to completely ignore either,” said University of Arizona astronomer Amy Mainzer, who specializes in asteroid detection and planetary defense.

The DART spacecraft was moved into a thermal vacuum chamber in February, to be subjected to extreme temperatures in preparation for conditions in space.

More than 90% of the potentially hazardous mountain-size asteroids have been identified, according to NASA. But only about 40% of potentially hazardous asteroids with diameters of 460 feet or more are believed to have been identified. There may be as many as 25,000 of these smaller asteroids, each of which might lay waste to an entire region if it were to strike our planet.

Asteroids 6 miles across or larger, like the one that wiped out most dinosaurs and torched much of the planet about 66 million years ago, are believed to strike only every 15 million years or so.

To facilitate the search for potentially hazardous asteroids, space agency officials in June approved the design of a new space-based infrared telescope called the Near-Earth Object Surveyor. The $500 million instrument is scheduled for launch in 2026.

“This is designed to find near-Earth asteroids large enough to cause regional damage,“ said Dr. Mainzer, who leads the project. “The question is to answer what could happen in the next 100 years. We hope the answer is nothing.”

Researchers have dreamed up various ways to eliminate the threat posed by asteroids, from obliterating them with nuclear-tipped missiles or burning them out of the sky with lasers to tugging them off course with the pull of gravity from a passing spacecraft. Some scientists have suggested unfurling solar sails on errant space rocks, so that the pressure of sunlight could alter their course.

The DART mission will test the simplest of these schemes—what space scientists call kinetic impact deflection—by steering the 1,200-pound, small-car-size probe into the moonlet with enough force to change its velocity by a fraction of a millimeter or so per second, according to Andy Rivkin, lead of the DART investigation team at the Applied Physics Laboratory. The action will be photographed by a free-flying, pint-size cubesat satellite designed by the Italian Space Agency, which the probe will release 10 days before the impact.

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**Chicxulub crater (from Wikipedia)**

The Chicxulub crater (English pronunciation /ˈtʃiːkʃʊluːb/ CHEEK-shuu-loob; Mayan: [tʃʼikʃuluɓ])[not verified in body] is an impact crater buried underneath the Yucatán Peninsula in Mexico.[3] Its center is located offshore near the communities of Chicxulub Puerto and Chicxulub Pueblo, after which the crater is named.[4] It was formed when a large asteroid, about 10 kilometers (6.2 miles) in diameter, struck the Earth.[5] The date of the impact coincides precisely with the Cretaceous–Paleogene boundary (commonly known as the "K–Pg boundary"), slightly more than 66 million years ago,[2] and a widely accepted theory is that worldwide climate disruption from the event was the cause of the Cretaceous–Paleogene extinction event, a mass extinction in which 75% of plant and animal species on Earth became extinct, including all non-avian dinosaurs.

The crater is estimated to be 150 kilometers (93 miles) in diameter[3] and 20 kilometers (12 miles) in depth, well into the continental crust of the region of about 10–30 kilometers (6.2–18.6 miles) in depth. It is the second largest confirmed impact structure on Earth, and the only one whose peak ring is intact and directly accessible for scientific research.[6]

The crater was discovered by Antonio Camargo and Glen Penfield, geophysicists who had been looking for petroleum in the Yucatán Peninsula during the late 1970s. Penfield was initially unable to obtain evidence that the geological feature was a crater and gave up his search. Later, through contact with Alan Hildebrand in 1990, Penfield obtained samples that suggested it was an impact feature. Evidence for the impact origin of the crater includes shocked quartz,[7] a gravity anomaly, and tektites in surrounding areas.

In 2016, a scientific drilling project drilled deep into the peak ring of the impact crater, hundreds of meters below the current sea floor, to obtain rock core samples from the impact itself. The discoveries were widely seen as confirming current theories related to both the crater impact and its effects.[8] A 2020 study concluded that the Chicxulub crater was formed by an inclined (45–60° to horizontal) impact from the northeast.[9]

Contents

In 1978, geophysicists Glen Penfield and Antonio Camargo were working for the Mexican state-owned oil company Petróleos Mexicanos, or Pemex, as part of an airborne magnetic survey of the Gulf of Mexico north of the Yucatán Peninsula.[10] Penfield's job was to use geophysical data to scout possible locations for oil drilling.[11] In the offshore magnetic data, Penfield noted anomalies whose depth he estimated and mapped. He then obtained onshore gravity data from the 1940s. According to Penfield, "The old data showed a large concentric set of onshore gravity anomalies. When I laid it next to my No. 2 pencil mapping of the offshore magnetic anomalies, the fit was perfect: a shallow, 180-kilometer diameter gravity-magnetic bullseye on the almost non-magnetic, uniform carbonate background of the Yucatan platform! We recognized the crater as the likely Cretaceous-Paleogene boundary event."[4][11] A decade earlier, the same map suggested an impact feature to contractor Robert Baltosser, but he was forbidden to publicize his conclusion by Pemex corporate policy of the time.[12]

Pemex disallowed release of specific data but let Penfield and company official Antonio Camargo present their results at the 1981 Society of Exploration Geophysicists conference.[13] That year's conference was underattended and their report attracted scant attention. Coincidentally, many experts in impact craters and the K–Pg (Cretaceous–Paleogene) boundary were attending a separate conference on Earth impacts. Although Penfield had plenty of geophysical data sets, he had no rock cores or other physical evidence of an impact.[11]

He knew Pemex had drilled exploratory wells in the region. In 1951, one bored into what was described as a thick layer of andesite about 1.3 kilometers (4,300 ft) down. This layer could have resulted from the intense heat and pressure of an Earth impact, but at the time of the borings it was dismissed as a lava dome—a feature uncharacteristic of the region's geology. Penfield tried to secure site samples, but was told such samples had been lost or destroyed.[11] When attempts at returning to the drill sites and looking for rocks proved fruitless, Penfield abandoned his search, published his findings and returned to his Pemex work.

At the same time, in 1980, geologist Walter Alvarez and his father, Nobel Prize–winning scientist Luis Walter Alvarez, put forth their hypothesis that a large extraterrestrial body had struck Earth at the time of the Cretaceous–Paleogene boundary. In 1981, unaware of Penfield's discovery, University of Arizona graduate student Alan R. Hildebrand and faculty adviser William V. Boynton published a draft Earth-impact theory and sought a candidate crater.[14] Their evidence included greenish-brown clay with surplus iridium containing shocked quartz grains and small weathered glass beads that looked to be tektites.[15] Thick, jumbled deposits of coarse rock fragments were also present, thought to have been scoured from one place and deposited elsewhere by a megatsunami resulting from an Earth impact.[16] Such deposits occur in many locations but seem concentrated in the Caribbean basin at the K–Pg boundary.[16] So when Haitian professor Florentine Morás discovered what he thought to be evidence of an ancient volcano on Haiti, Hildebrand suggested it could be a telltale feature of a nearby impact.[17] Tests on samples retrieved from the K–Pg boundary revealed more tektite glass, formed only in the heat of asteroid impacts and high-yield nuclear detonations.[17]

In 1990, Houston Chronicle reporter Carlos Byars told Hildebrand of Penfield's earlier discovery of a possible impact crater.[18] Hildebrand contacted Penfield in April 1990 and the pair soon secured two drill samples from the Pemex wells, stored in New Orleans.[19] Hildebrand's team tested the samples, which clearly showed shock-metamorphic materials.

A team of California researchers including Kevin Pope, Adriana Ocampo, and Charles Duller, surveying regional satellite images in 1996, found a cenote (sinkhole) ring centered on Chicxulub that matched the one Penfield saw earlier; the cenotes were thought to be caused by subsidence of bolide-weakened lithostratigraphy around the impact crater wall.[20] More recent evidence suggests the crater is 300 km (190 mi) wide, and the 180-kilometre (110 mi) ring is an inner wall of it.[21]

The Chicxulub impactor had an estimated diameter of 11–81 kilometers (6.8–50.3 mi), and delivered an estimated energy of 21–921 billion Hiroshima A-bombs (between 1.3×1024 and 5.8×1025 joules, or 1.3–58 yottajoules).[23] For comparison, this is ~100 million times the energy released by the Tsar Bomba, a thermonuclear device ("H-bomb") that remains the most powerful human-made explosive ever detonated, which released 210 petajoules (2.1×1017 joules, or 50 megatons TNT).[24] Other estimates find the impact had an energy of 3×1023 joules.[25] The impact created a hole 100 kilometers (62 mi) wide and 30 kilometers (19 mi) deep, leaving a crater mainly under the sea and covered by 600 meters (2,000 ft) of sediment by the 21st century.[26] In addition, the impact created winds in excess of 1,000 kilometres per hour (620 mph) near the blast's center.[27]

One example of recent parameter estimates is in a 2020 study,[9] informed by data from crater core samples (taken by IODP-ICDP Expedition 364 in 2016). The authors simulate one scenario using an impactor that is 17 km in diameter, with a density of 2,650 kg/m3 and therefore a mass of about 6.82×1015 kg, striking Earth at 12 km/s with an angle of 60° from horizontal. In another scenario that also approximately matches the evidence they analyzed, they simulate an impactor that is 21 km in diameter, with a mass of 1.28×1016 kg, a speed of 20 km/s, and an impact angle of 45°. These values illustrate one set of experts' estimates based on current evidence and density parameter approximating that of a carbonaceous chondrite asteroid, often considered the likely type of the impactor.

The impact would have caused a megatsunami over 100 meters (330 ft) tall[28] that would have reached all the way to what are now Texas and Florida.[29] The height of the tsunami was limited by the relatively shallow sea in the area of the impact; in deep ocean it would have been 4.6 kilometers (2.9 mi) tall.[28] Nonetheless, the most recent simulations show that waves may have been up to 1.5 kilometers (~1 mi) tall, able to reach the coastal lines all over the world.[30] David Shonting and Cathy Ezrailson propose a particular mechanism triggering the megatsunami, the "Edgerton effect", analogous to a milk drop falling onto a wet table taken by Professor Harold Edgerton of the Massachusetts Institute of Technology: at the moment of the impact, the drop disappears and a crown-shape water column, with a similar height to the original droplet, is raised up, and in case of the Chicxulub impactor this implies a height of over 10–12 km for the initial seawater forced outward by the explosion and blast waves; its collapse triggers megatsunamis changing their height according to the different water depth.[31] In reality, many types of tsunamis were triggered, with two main megatsunamis generated, respectively, by the direct blast and expansion of the transient crater and by the outward expansion of oceanic water after filling the crater (both 100–300 meters tall); two other kind of tsunamis, tens of meters tall, were triggered by massive slumps and landslides for seismic waves around the Gulf of Mexico and directly by seismic waves. There may have been back and forth tsunamis in time.[32][30][33][34]

A cloud of hot dust, ash and steam would have spread from the crater as the impactor burrowed underground in less than a second.[35] Excavated material along with pieces of the impactor, ejected out of the atmosphere by the blast, would have been heated to incandescence upon re-entry, broiling the Earth's surface and possibly igniting wildfires; meanwhile, colossal shock waves would have triggered global earthquakes and volcanic eruptions.[36] Fossil evidence for an instantaneous die-off of diverse animals was found in a soil layer only 10 centimeters (3.9 in) thick in New Jersey 5,000 kilometers (3,100 mi) away from the impact site, indicating that death and burial under debris occurred suddenly and quickly over wide distances on land.[26] Field research from the Hell Creek Formation in North Dakota published in 2019[37] shows the simultaneous mass extinction of myriad species combined with geological and atmospheric features consistent with the impact event. According to researchers, the impact triggered a seismic event equivalent to a Magnitude 12 earthquake at the impact site, with shockwaves generating the equivalent of Magnitude 9 earthquakes across the globe. In addition, the ensuing shockwaves likely triggered large-scale volcanic eruptions across the Earth; the shockwaves probably contributed to the Deccan Traps flood basalt eruption, which was estimated to have occurred around the same time.[38] Other researchers find that the Chicxulub impact was magnitude 9 – 11 on the richter scale.[39]

The emission of dust and particles could have covered the entire surface of the Earth for several years, possibly a decade, creating a harsh environment for living things. Production of carbon dioxide caused by the destruction of carbonate rocks would have led to a sudden greenhouse effect.[40] Over a decade or longer, sunlight would have been blocked from reaching the surface of the Earth by the dust particles in the atmosphere, cooling the surface dramatically. Photosynthesis by plants would also have been interrupted, affecting the entire food chain.[41][42] A model of the event developed by Lomax et al. (2001) suggests that net primary productivity (NPP) rates may have increased to higher than pre-impact levels over the long term because of the high carbon dioxide concentrations.[43]

In February 2008, a team of researchers led by Sean Gulick at the University of Texas at Austin's Jackson School of Geosciences used seismic images of the crater to determine that the impactor landed in deeper water than previously assumed. They argued that this would have resulted in increased sulfate aerosols in the atmosphere. According to the press release, that "could have made the impact deadlier in two ways: by altering climate (sulfate aerosols in the upper atmosphere can have a cooling effect) and by generating acid rain (water vapor can help to flush the lower atmosphere of sulfate aerosols, causing acid rain)."[44] This was borne out by the results of a drilling project in 2016 which found that sulfate-containing rocks found in the area were not found in the peak ring (the rocks found were from deep within the earth's crust instead), the interpretation being that they had been vaporized by the impact and dispersed into the atmosphere.

Geology and morpholog

The piece of clay, held by Walter Alvarez, that sparked research into the impact theory. The greenish-brown band in the center is extremely rich in iridium.

In their 1991 paper, Hildebrand, Penfield and company described the geology and composition of the impact feature.[46] The rocks above the impact feature are layers of marl and limestone reaching to a depth of almost 1,000 m (3,300 ft). These rocks only date back as far as the Paleocene (56 to 66 millions years before present) and were therefore deposited after the impact.[47] Below these layers lie more than 500 m (1,600 ft) of andesite glass and breccia. These andesitic igneous rocks were only found within the supposed impact feature, as is shocked quartz.[47] The K–Pg boundary inside the feature is depressed to 600 to 1,100 m (2,000 to 3,600 ft) compared with the normal depth of about 500 m (1,600 ft) measured 5 km (3 mi) away from the impact feature.[48]

Along the edge of the crater are clusters of cenotes or sinkholes,[49] which suggest that there was a water basin inside the feature during the Neogene period, after the impact.[48] The groundwater of such a basin would have dissolved the limestone and created the caves and cenotes beneath the surface.[50] The paper also noted that the crater seemed to be a good candidate source for the tektites reported at Haiti.[51]

The impactor is widely agreed to be of carbonaceous chondritic composition, based on geochemical evidence.[5] In 1998 a 2.5 mm sized meteorite was described from the North Pacific from sediments spanning the Cretaceous-Paleogene boundary, that was suggested to represent a fragment of the Chicxulub impactor. Analysis suggested that it best fit the criteria of CV, CO and CR carbonaceous chondrites.[52]

In September 2007, a report published in Nature proposed an origin for the asteroid that created the Chicxulub crater.[41] The authors, William F. Bottke, David Vokrouhlický, and David Nesvorný, argued that a collision in the asteroid belt 160 million years ago resulted in the Baptistina family of asteroids, the largest surviving member of which is 298 Baptistina. They proposed that the "Chicxulub asteroid" was also a member of this group. The connection between Chicxulub and Baptistina is supported by the large amount of carbonaceous material present in microscopic fragments of the impactor, suggesting the impactor was a member of an uncommon class of asteroids called carbonaceous chondrites, like Baptistina.[53] According to Bottke, the Chicxulub impactor was a fragment of a much larger parent body about 170 km (106 mi) across, with the other impacting body being around 60 km (37 mi) in diameter.[53][54]

In 2011, new data from the Wide-field Infrared Survey Explorer revised the date of the collision which created the Baptistina family to about 80 million years ago. This makes an asteroid from this family highly improbable to be the asteroid that created the Chicxulub crater, as typically the process of resonance and collision of an asteroid takes many tens of millions of years.[55] In 2010, another hypothesis was offered which implicated the newly discovered asteroid 354P/LINEAR, a member of the Flora family of asteroids, as a possible remnant cohort of the K/Pg impactor.[56]

In February 2021, newly published data from four independent laboratories showed elevated concentrations of iridium in the crater's peak ring, further corroborating the asteroid impact hypothesis.[57] In the same month Avi Loeb and a colleague published a study in Scientific Reports suggesting the impactor was a fragment from a disrupted comet, rather than an asteroid which has long been the leading candidate among scientists.[58][59] This was followed by a rebuttal in June of the same year, which charged that the paper ignored key geochemical evidence that made a comet incompatible with known data, and suggested based on multiple lines of evidence that the impactor was either a CM or CR carbonaceous chondrite C-type asteroid.[5] In July 2021, a study reported that the impactor likely originated in the outer main part of the asteroid belt, based on numerical simulations.[60][61]

The Chicxulub crater lends support to the theory postulated by the late physicist Luis Alvarez and his son, geologist Walter Alvarez, that the extinction of numerous animal and plant groups, including non-avian dinosaurs, may have resulted from a bolide impact (the Cretaceous–Paleogene extinction event). Luis and Walter Alvarez, at the time both faculty members at the University of California, Berkeley, postulated that this enormous extinction event, which was roughly contemporaneous with the postulated date of formation for the Chicxulub crater, could have been caused by just such a large impact.[62] The age of the rocks marked by the impact shows that this impact structure dates from roughly 66 million years ago, the end of the Cretaceous period, and the start of the Paleogene period. It coincides with the K–Pg boundary, the geological boundary between the Cretaceous and Paleogene. The impact associated with the crater is thus implicated in the Cretaceous–Paleogene extinction event, including the worldwide extinction of non-avian dinosaurs. This conclusion has been the source of controversy.

In March 2010, forty-one experts from many countries reviewed the available evidence: 20 years' worth of data spanning a variety of fields. They concluded that the impact at Chicxulub triggered the mass extinctions at the K–Pg boundary.[63][64] In 2013 a study compared isotopes in impact glass from the Chicxulub impact with the same isotopes in ash from the boundary where the extinction event occurred in the fossil record; the study concluded that the impact glasses were dated at 66.038 ± 0.049 Ma, and the deposits immediately above the discontinuity in the geological and fossil record was dated to 66.019 ± 0.021 Ma, the two dates being within 19,000 years of each other, or almost exactly the same within experimental error.[22]

The theory is now widely accepted by the scientific community. Some critics, including paleontologist Robert Bakker, argue that such an impact would have killed frogs as well as dinosaurs, yet the frogs survived the extinction event.[65] Gerta Keller of Princeton University argues that recent core samples from Chicxulub prove the impact occurred about 300,000 years before the mass extinction, and thus could not have been the causal factor.[66] This conclusion is unsupported by radioactive dating and sedimentology.[63][22]

The main evidence of such an impact, besides the crater itself, is contained in a thin layer of clay present in the K–Pg boundary across the world. In the late 1970s, the Alvarezes and colleagues reported that it contained an abnormally high concentration of iridium.[67] Iridium levels in this layer reached 6 parts per billion by weight or more compared with 0.4 for the Earth's crust as a whole;[68] in comparison, meteorites can contain around 470 parts per billion of this element.[69] It was hypothesized that the iridium was spread into the atmosphere when the impactor was vaporized and settled across the Earth's surface among other material thrown up by the impact, producing the layer of iridium-enriched clay.[70] Similarly, an iridium anomaly in core samples from the Pacific Ocean suggested the Eltanin impact of about 2.5 million years ago.[71][72]

A more recent discovery is believed to demonstrate evidence of the scope of the destruction from the impact. In a March 2019 article in the Proceedings of the National Academy of Sciences, an international team of twelve scientists revealed the contents of the Tanis fossil site discovered near Bowman, North Dakota that appeared to show the destruction of an ancient lake and its inhabitants at the time of the Chicxulub impact. In the paper, the group claims that the geology of the site is strewn with fossilized trees and remains of fish and other animals. The lead researcher, Robert A. DePalma of the University of Kansas, was quoted in the New York Times as stating that "you would be blind to miss the carcasses sticking out... It is impossible to miss when you see the outcrop." Evidence correlating this find to the Chicxulub impact included tektites bearing "the unique chemical signature of other tektites associated with the Chicxulub event" found in the gills of fish fossils and embedded in amber, an iridium-rich top layer that is considered another signature of the event, and an atypical lack of scavenging of the dead fish and animals that suggested few other species survived the event to feed off the mass death. The exact mechanism of the site's destruction has been debated as either an impact-caused tsunami or lake and river seiche activity triggered by post-impact earthquakes; there has yet been no firm conclusion upon which researchers have settled.[73][74]

In recent years, several other craters of around the same age as Chicxulub have been discovered, all between latitudes 20°N and 70°N. Examples include the disputed Silverpit crater in the North Sea, and the Boltysh crater in Ukraine.[75][76][77] Both are much smaller than Chicxulub, but are likely to have been caused by objects many tens of meters across striking the Earth.[78] This has led to the hypothesis that the Chicxulub impact may have been only one of several impacts that happened nearly at the same time.[79] Another possible crater thought to have been formed at the same time is the larger Shiva crater, though the structure's status as an impact crater is contested.[80][81]

The collision of Comet Shoemaker–Levy 9 with Jupiter in 1994 demonstrated that gravitational interactions can fragment a comet, giving rise to many impacts over a period of a few days if the comet should collide with a planet. Comets undergo gravitational interactions with the gas giants, and similar disruptions and collisions are very likely to have occurred in the past.[80][82] This situation may have occurred on Earth at the end of the Cretaceous, though Shiva and the Chicxulub craters might have been formed 300,000 years apart.[79][80]

In late 2006, Ken MacLeod, a geology professor from the University of Missouri, completed an analysis of sediment below the ocean's surface, bolstering the single-impact theory. MacLeod conducted his analysis approximately 4,500 kilometers (2,800 mi) from the Chicxulub crater to control for possible changes in soil composition at the impact site, while still close enough to be affected by the impact. The analysis revealed there was only one layer of impact debris in the sediment, which indicated there was only one impact.[83] Multiple-impact proponents such as Gerta Keller regard the results as "rather hyper-inflated" and do not agree with the conclusion of MacLeod's analysis, arguing that there might only be gaps of hours to days between impacts in a multiple-impact scenario (cf. Shoemaker-Levy 9) which would not leave a detectable gap in deposits.[84]

Chicxulub is the only known Earth crater with a remaining impact peak ring, but it is under 600 m (2,000 ft) of sediment.[85] During April and May 2016, a joint IODP-ICDP[86][87] Mission Specific Platform Expedition no. 364 obtained the first offshore core samples from the peak ring, surrounding the central zone of the crater.[88] During Expedition 364, DES[89] drillers on the L/B Myrtle[90] collected core samples to enable ECORD[91] Science Party members to study how the peak ring formed and calculate the total impact energy.

Their target depth was 1,500 m (4,900 ft) below the bottom of the ocean,[92] but they reached an acceptable 1,335 m (4,380 ft).[88] Sample preparation and analysis were performed in Bremen, Germany.[85]

It was announced in November 2016 that pink granite, usually found deep in the Earth's crust, had been found in drilling samples.[6][93] It suggests the impact was so great it shocked and melted rocks found deep in the crust, causing them to shoot up before falling back down to produce the peak rings.[6][93] The granite samples were also found to be lighter and weaker than normal granite, a result of the shock and extreme conditions of the impact.[94] The findings confirmed that the rock comprising the peak ring had originated deep in the earth, and was ejected to the surface.[6] It had been subjected to immense pressures and forces and had been melted by heat and shocked by pressure from its usual state into its present form in just minutes; the fact that the peak ring was made of granite was also significant, since granite is not a rock found in sea-floor deposits, originating much deeper in the earth, and had been ejected to the surface by the immense pressures of the impact.[93]

Gypsum, a sulfate-containing rock usually present in the shallow seabed of the region, had been almost entirely removed and likely vaporized to enter the atmosphere, an event immediately followed by a megatsunami sufficient to lay down the largest-known layered bed of sand, around 100 m (330 ft) deep and separated by grain size, directly above the peak ring.[95] These types of sand deposits are caused by extreme water movement, where the larger and heavier sand grains settle first, followed by lighter and smaller grains.

Taken together, analyses indicate that the impactor was large enough to create a 190-kilometer (120 mi) peak ring, to melt, shock and eject granite from many kilometers within the earth, to create colossal water movements, and to eject an immense quantity of vaporized rock and sulfates into the atmosphere, where they would have persisted over years to decades.[6][95] This global dispersal of dust and sulfates would have led to a sudden and catastrophic effect on the climate worldwide, large temperature drops, and devastated the food chain. The researchers stated that the impact generated an environmental calamity that extinguished life, but it also induced a vast subsurface hydrothermal system that became an oasis for the recovery of life.[93][96]

A program on British television in 2017[97] described that the drilling revealed, from top down: thick Cenozoic limestone, about 600 m (2,000 ft); a graded sediment deposit from the megatsunami, over 100 m (330 ft) thick; the impact melted basement granite from the Earth's midcrust with shocked quartz. The peak ring itself did not contain the calcium sulfate that the rocks in the area around contain, leading the program makers to conclude that all the calcium sulfate in the crater area had been vaporized into the atmosphere and had become a dense sulfur dioxide veil stopping the sunlight. As additional clues of the resulting megatsunami found in a New Jersey, US quarry, a dense marine bone bed was found on the Cretaceous–Paleogene boundary containing a mixture of dead sea animals with little or no damage from scavengers or predators. Also related to this tsunami was a dense dinosaur bone bed on the Cretaceous–Paleogene boundary found in Patagonia.

A 2020 study mentioned that Expedition 364 drilled to a depth of 1,335 m (4,380 ft) below the sea floor to reach the peak ring, and discovered a massive hydrothermal system filled with magma, which modified ~1.4 × 105 km3 of Earth's crust and lasted for hundreds of thousands of years; in addition, those hydrothermal systems might support the impact origin of life hypothesis for the Hadean,[98] when the entire surface of Earth was affected by impactors enormously larger than the Chicxulub impactor.[99]

***[https://www.wsj.com/articles/nasas-asteroid-defense-mission-to-smash-probe-into-distant-space-rock-11637679600?st=1w32c38fqxet1al&reflink=article\_gmail\_share](https://www.wsj.com/articles/nasas-asteroid-defense-mission-to-smash-probe-into-distant-space-rock-11637679600?st=1w32c38fqxet1al&reflink=article_gmail_share" \t "_blank)***