Podcast: Aftermath of the Chicxulub asteroid

PNAS: Welcome again to Science Sessions. I'm Brian Doctrow.

Approximately 66 million years ago, Earth's Cretaceous period ended with a bang. An asteroid, tens of kilometers in diameter, slammed into what is now the Yucatan Peninsula of Mexico at more than 40,000 miles per hour. The resulting impact, known as the Chicxulub impact after a Mexican town located near the impact site, released a billion times more energy than the atomic bomb dropped on Hiroshima and left a crater approximately 180 km wide. The long-term consequences of this impact, including a worldwide reduction in sunlight and global cooling that lasted for years, are generally believed to have caused the extinction of approximately three-quarters of all species on Earth, including the dinosaurs. What hasn't been clear, though, is what happened in the hours immediately following the impact. That began to change in the summer of 2012, when Robert DePalma, the Curator of Paleontology for the Palm Beach Museum of Natural History and a graduate student at the University of Kansas, began excavating a sediment deposit in the Hell Creek Formation in southwestern North Dakota. He was drawn to the Hell Creek initially by reports of a large number of intact, well-preserved animal carcasses at the site.

DePalma: Before this site had ever been excavated, there were approximately three to four complete fossil fish known from the Hell Creek Formation. And here we've got dozens, actually hundreds of different fish, representing multiple species, some of which have not even been named yet.

PNAS: Before long, however, DePalma began to realize that there was far more to the site, which he named Tanis. For one thing, the animal remains included a mix of marine and freshwater species. At the time the sediments were deposited, during the Late Cretaceous, a shallow inland sea, the Western Interior Seaway, extended from the Gulf of Mexico through the central United States. But Tanis itself would have been in a freshwater riverbed. So what were sea-dwelling animals doing there? And mixed in with the sediment were tektites: bits of glass formed when a meteorite impact melts the surrounding rock and subsequently ejected from the impact crater. And there was more evidence linking the deposit to the Chicxulub impact: the deposit sits just below a thin layer of iridium-rich clay made of fine-grained fallout from the impact, and which marks the boundary between the Cretaceous and Paleogene periods, known as the K-Pg, or K-T, boundary. The apparent rapid sediment deposition and burial of the fish, coupled with the presence of the tektites and the proximity to the K-Pg boundary, raised the possibility that the deposit could be the record of a massive inundation that was triggered by the Chicxulub impact itself.

At this point, DePalma reached out to two experts on the Chicxulub impact: Walter Alvarez, at the University of California, Berkeley, who first hypothesized that an asteroid impact could have caused the mass extinction at the end of the Cretaceous; and Jan Smit, at Vrije Universiteit Amsterdam. Smit recalls his first contact with DePalma.

Smit: He showed me first this beautiful piece where you see two fishes together with the shell of an ammonite, which is a squid that lives in the sea. They don't co-occur together in that state, the freshwater fishes together with a marine fossil. Then he sent me his sketch of the outcrop showing definitely two surges working up the river. And then again he showed me that he had found the glasses from the impact itself. I get contacted by many people who think they have found something in the Western Interior, and usually it's nothing. But this time I started to believe it and I said, “I have to go there.”

PNAS: DePalma recruited a team of scientists to study the Tanis site. The results of their analyses were recently published in PNAS. One of the researchers who joined the study was a former student of Smit’s, Johan Vellekoop, now at the Catholic University of Leuven, who specializes in fossils of marine microorganisms. The Tanis deposit contained fossilized remains of a type of microscopic marine algae called dinoflagellates. Analysis of these dinoflagellates constrained the timing of the deposit to around the time of the Chicxulub impact, and provided further evidence for a high-energy inundation from the sea.

Vellekoop: We basically had dinoflagellates that are strictly Late Maastrichtian age, so just before the impact. But we also had fossils that were millions of years older, all mixed in together. So this tells me that these sediments deposited at this site were a mixture of contemporary burial, mixed in with older sediments being reworked into the strata. So lots of waves pushing in material, both contemporary organisms but also old sand that has been laying on the sea floor for millions of years.

PNAS: Another key piece of evidence for the timing of the event was the tektites. Close analysis of the tektites seemed to suggest that they had landed at Tanis directly from the impact, rather than landing elsewhere and then being carried to Tanis by the inundation. For one thing, some of the fish found at the site had tektites in their gills. Smit explains.

Smit: One of these fishes, the paddlefish, the way he collects his food, he swims in the river with an open mouth. And the only way the tektites could be caught in his gills is by the fish swimming in the river while the tektites are falling from the sky.

PNAS: But how did the researchers know that the tektites came specifically from the Chicxulub impact? Although the chemical composition of the tektites undergoes changes after tens of millions of years, Smit and DePalma say a few of the tektites at Tanis remained unaltered in their cores, enabling their original elemental composition to be determined.

Smit: We know the composition of the crust where the Chicxulub meteorite landed fairly well. If you melt this crust and create glass from it, you know, more or less, by analyzing the glass, what type of crust it was.

DePalma: In this case, the geochemistry of the ejecta in the deposit matches Chicxulub ejecta from other K-T boundary sites. In addition, there are some pieces of unaltered

impact glass associated with this site, and we have argon-argon dated that glass and discovered that the date matches the date of the Chicxulub impact.

PNAS: The presence of tektites from the Chicxulub impact throughout the inundation deposit enabled the researchers to estimate when the inundation occurred relative to the impact.

DePalma: If we do physics calculations of that accumulation of ejecta, when would that arrive from the impact site? Arrival of that ejecta would have occurred within roughly 13 minutes to two hours after impact, maximum. It's very, very rare to get that sort of temporal resolution in the fossil record.

PNAS: A massive inundation of the river occurring within two hours of the Chicxulub impact raised the intriguing possibility that the impact itself might have caused the inundation. Evidence of a tsunami caused by the Chicxulub impact has already been documented at other sites, and the Tanis deposit resembles a tsunami deposit. But the idea of a tsunami reaching Tanis all the way from the Gulf of Mexico is problematic for a number of reasons.

DePalma: If one were to extrapolate how long a tsunami would take to get to the Tanis region from Chicxulub, they'd come up with a figure well beyond 10 hours, more like 17 to 20 hours after impact. By contrast, the ejecta in our deposit demonstrates that the Tanis site was formed well before a tsunami could have reached there.

PNAS: It was Mark Richards, a geophysicist at the University of California, Berkeley, who, during conversations with Smit, proposed an alternative mechanism for the inundation. Richards proposed a mechanism called a seiche, which was consistent with the observed timing.

Smit: He showed me a small movie, which was made in a Norwegian fjord in 2011, about half an hour after the devastating earthquake in Japan. And you see the waters of the fjords in Norway were set in motion by the earthquake movements eight thousand kilometers away. And that was within half an hour from the earthquake in Japan.

PNAS: In a seiche, seismic waves, like those from an earthquake or meteorite impact, cause the ground around a body of water to vibrate, which in turn generates standing waves in the water within.

DePalma: If you get a deep pan full of water and you jerk it toward you very quickly, that entire body of water will move and slosh as one body in the pan. And essentially you get a very similar thing that occurs at great scale with large bodies of water.

Smit: They are set in motion by movement of the surroundings, which is coupled to a body of water, which then starts to slosh back and forth.

PNAS: Notably, seismic waves travel much faster than a wave through water.

DePalma: When we did the calculations of the seismic wave propagation from the Chicxulub impact site, we discovered that seismic waves arrived at Tanis within the first

half hour after impact. That coincides almost perfectly with the time interval that is determined by the ejecta within the deposit. In other words, the deposit was forming right around the same time that the seismic waves arrived from Chicxulub. Knowing that seismic waves are capable of causing massive inundations due to seiche activity, we conclude that it was very likely that a seiche was responsible for the deposit at Tanis and that that seiche was in fact initiated by seismic waves from the Chicxulub event.

PNAS: Taken together, the Tanis site presents a unique window into what may have happened in the minutes and hours immediately after the Chicxulub impact.

DePalma: Because we have sediments that preserve really, really high temporal resolution, we can essentially show what happened in western North America right after impact. It's essentially the same thing as having a high-speed video of one of the most interesting events in prehistory.

PNAS: Peter Larson, the president of the Black Hills Institute of Geological Research in South Dakota, who assisted with the excavations, is emphatic about the significance of the find.

Larson: Well, it's the first time we have evidence of animals whose death is directly attributable to the impact. It's something that I think everybody who researches the K-Pg boundary has always wanted to find. But of course finding a site that preserves the carcasses that were killed by the impact is almost an impossibility. This is a one in a billion chance that this would have ever been found.

PNAS: Paul Renne, the director of the Berkeley Geochronology Center in California, who was not involved in the research but who has worked closely with some of the authors, was similarly thrilled with the results.

Renne: The paper in question was really exciting in the sense that this is a phenomenal assemblage of fossils in their dynamic context. We would say in the biz that it's a taphonomical paradise. Taphonomy refers to the arrangement of fossils and how they indicate something about the environment and the contextual dynamics of that environment. This is just sensational.

PNAS: However, Renne emphasizes that the findings, as fascinating as they are, may not reveal how the impact contributed to mass extinction globally.

Renne: What you're looking at is what happened in one locality. One would expect that this was a much more widespread phenomenon. But whether or not this is emblematic of how such a large portion of life on earth was affected, I don't think it really is.

PNAS: Kirk Johnson, the Sant Director of the Smithsonian's National Museum of Natural History in Washington, DC, who was also not involved in the research, thinks that the seiche hypothesis could provide context for other fossils from the same time period.

Johnson: The idea that it was, transmitted seismicity from the Chicxulub impact is a very compelling idea. It does make me think about looking at adjacent sites more carefully. And we've seen in that same region, a bunch of sites that have, for instance, these marine dinoflagellates. We always wondered, how did they get in place? This site seems to suggest that something was happening that was moving marine organisms far inland.

PNAS: Nevertheless, Johnson would like to see more details about the particular marine animals that were found.

Johnson: Some of these really critical things are shown with a single hard-to-read illustration in the supplementary data. So the ammonite, for instance–you can see it in one picture, but there's no anatomy showing that it is in fact an ammonite. So I think some of the key biologic elements of the story need to be more exposed in publications.

PNAS: The authors emphasize that the PNAS article is only the first chapter of what might turn out to be a saga of global mass extinction. Additional fossils found at the site, which will be described in subsequent papers, may provide a glimpse into the local ecology at the time of the impact.

Smit: This Tanis site preserves a snapshot of life as we know it in the very latest Cretaceous.

Larson: It is a site that's going to keep on giving. Probably Robert will be publishing papers on this through his entire career because there's just so much more to learn there and so much to tell people about. Stay tuned, there's going to be more!

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