Blue Holes & Hurricanes

GEOLOGICAL MARVELS ARE GOLD MINES FOR CLIMATE HISTORY

by David Levin

With WHOI's research vessel *Atlantis* anchored in Discovery Bay off Jamaica, a team of WHOI scientists is towed on a small boat to a blue hole in shallower waters. They use long pipes to core into sediments that settled to the bottom of the blue hole. The sediments contain forensic clues that the scientists use to reveal past patterns of hurricane and ocean temperatures, which can help us predict and prepare for hurricane activity in the future.

Richard Sullivan, WHOI

A blue hole in the ocean is a striking sight. Fly over remote areas of the Caribbean Sea and you'll see shallow turquoise water stretching for miles, interrupted only by occasional sand bars and coral reefs. In a few rare spots, though, the ocean floor suddenly falls away hundreds of feet into a round, gaping, steep-walled maw big enough to swallow a small ship. The dark blue color of the deeper waters in these submerged caverns contrasts dramatically with the sapphire hues of shallower waters nearby.

These sinkholes, framed by limestone, formed on dry land during the last ice age, when much of the Earth's water was frozen in massive ice sheets on land and sea levels were almost 400 feet lower than today. Limestone is easily erodible, and groundwater trickling through it carved away huge underground caverns. Their roofs eventually caved in, leaving deep shafts open in the Earth. When the ice age ended and sea levels rose again, these holes flooded, creating deep vertical caverns in what is now the seafloor.

Although these features are geological marvels, that's not the main reason Jeff Donnelly, a geologist at Woods Hole Oceanographic Institution, studies them. Blue holes also hold evidence of hurricanes that swept over the Atlantic in the past.


Nicole D'Entremont, WHOI

Donnelly has been working on reconstructing a history of storms going back thousands of years. As a hurricane passes over the coast, high winds and waves push huge amounts of sand and other debris into or off of coastal barrier beaches and shoreline ponds. Layers of that hurricane debris are buried over time.

But Donnelly and his colleagues can uncover it by taking samples of sediments near the coast. They push long metal and plastic tubes into the muck—like an apple corer into an apple—and pull out a plug of intact sediments. In this way, they can reveal distinct layers of sand and debris swept in by storms centuries ago, giving them a virtual timeline of extreme weather. The deeper the layer, the further back in time they go.

Over the last 15 years, Donnelly and colleagues have found valuable clues to ancient storms that hit the eastern coast of the United States. Still, he said, that tells them little about hurricanes that passed throughout wider regions of the North Atlantic Ocean during that time.

That's where blue holes come in. As deep, relatively narrow pits, they form perfect natural sediment traps, Donnelly said—whatever falls in generally doesn't come back out. In these placid bodies of water, sediments can settle and remain undisturbed for millennia. They add up to a potential gold mine of information, revealing patterns of past hurricane activity and clues to predict how frequent and intense hurricanes may be in the future.

"The trillion-dollar question is, 'what are the climate phenomena that come together to give us intervals of hurricane activity?'" Donnelly said.

X marks the spots

Finding blue holes is a challenge in itself. Many are uncharted, or they exist only on 19th-century British navigation charts. To locate coring sites, Donnelly and his team began combing through satellite images, looking for telltale dark spots in the otherwise crystal-blue Caribbean.

"Jeff is the master of the big picture," said Stephanie Madsen, who until recently worked as Donnelly's research assistant. "He gets on Google Earth and searches all over the world to figure out where hurricanes would possibly track, where there's a great location that would preserve that hurricane in sediments, and where we would have access to these sediments to core."

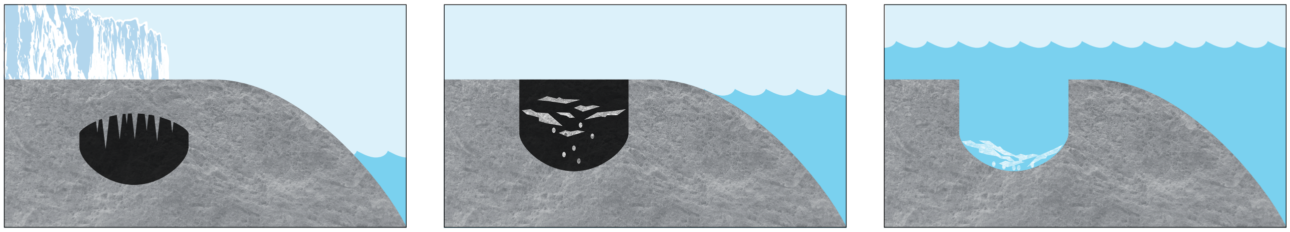
Donnelly and his team weeded out the blue holes that seemed both most promising and most accessible to investigate. Lab members did basic reconnaissance on about 25 potential sites, and Madsen began to spearhead the logistics of getting a team of scientists, students, and equipment down to the Bahamas.

Collecting equipment for a coring mission like this, she notes, is no small task: "There's no website for geologic research where you can order everything needed for coring," she said. "It's basically MacGyver-style makeshift equipment. We had to go to plumbing shops, floral supply shops for core foam, irrigation supply shops for tubing, concrete supply stores for shafts and vibrating motors—and then piece it all together."

Once the equipment arrived, the researchers had to get it out to the coring sites at sea. Through grants from the Dalio Foundation and the Dalio Ocean Initiative, which supports marine exploration, the team had access to *Alucia*, a 185-foot research vessel outfitted with two submersibles. During Donnelly's research cruise in April 2016, a film crew documented his team's work, eventually developing a show that aired in November 2016 as part of the National Geographic Channel's "Years of Living Dangerously" series.

"The *Alucia* gave us access to remote sites where a larger ship typically can't get in and would have been exceedingly difficult to get to otherwise," Donnelly said. "In even tighter places, we craned our 20-foot-long coring boat, *Arenaria*, into the water to reach coring sites."

Anatomy of a Blue Hole Illustration by Eric S. Taylor, WHOI Graphic Services



In ice ages, more of Earth's water was frozen in ice sheets, lowering sea levels. Groundwater eroded underground caverns in limestone.

The caverns' roofs eventually caved in, creating deep holes.

When the ice age ended, sea levels rose—submerging the land and creating blue holes in what is now the seafloor.

Smoking guns on the seafloor

The next several weeks proved to be a whirlwind of activity, from filming documentary segments to lowering 15-meter (50-foot) metal coring tubes into deep blue holes from *Arenaria*.

"Usually we arrived at the site at seven in the morning and stayed until sundown. But we'd maybe only get two to three cores out of the day," said Lizzie Wallace, a graduate student in the MIT-WHOI Joint Program in Oceanography. Lowering cores into a deep blue hole, she said, could sometimes take an hour and a half—and getting something back wasn't always guaranteed. "Some of the time, when we were bringing it up, the pressure from pulling the tube out of the mud or bedrock would shear the aluminum core in half. It would just come up as an empty tube. But we're used to that—it's not atypical of what happens in the field," she said.

Despite these setbacks, the team amassed dozens of cores throughout the Caribbean, in some cases reaching more than 60 feet into the sediments at the bottom of blue holes, collecting sediment that was laid down more than 1,600 years ago.

"Most of that sediment is very fine-grained," said Donnelly. "Whatever the tidal currents and waves generate makes its way into that basin and falls to the bottom. But when a hurricane strikes, it starts moving large particles into the hole, and you get an 'event bed' of very coarse material"—a layer indicating a hurricane.

"Not only is there sediment falling down, there's also mangrove leaves and twigs and other organic debris embedded in each layer that we can use to carbon-date them," Donnelly said.

WHOI geologist Jeff Donnelly peers out of the glass sphere of a submersible descending into a blue hole in the Caribbean Sea.

In addition, tiny shells of dead marine life also fall into blue holes and are preserved as fossils. The shells offer another trove of crucial information, said Pete van Hengstum of Texas A&M University at Galveston, who is collaborating on the research. The chemistry of the shells changes as ocean water temperatures change, he said, so by dating and analyzing the shells, scientists can reveal a timeline of past ocean temperatures.

"We effectively have a history going back 1,600 years of hurricanes that were intense enough and close enough to a blue hole to leave a record," Donnelly said. By repeating this coring in multiple locations, he noted, it's possible to slowly build a picture of ancient weather and ocean temperatures—and, by extension, ancient climate—along the western Atlantic.

Uncovering long-buried trends

In August 2016, Donnelly and his team collected more blue-hole cores from Jamaica aboard WHOI's research vessel *Atlantis*, providing even more evidence for ancient storms. Some surprising patterns, he said, have emerged within the blue hole sediments.

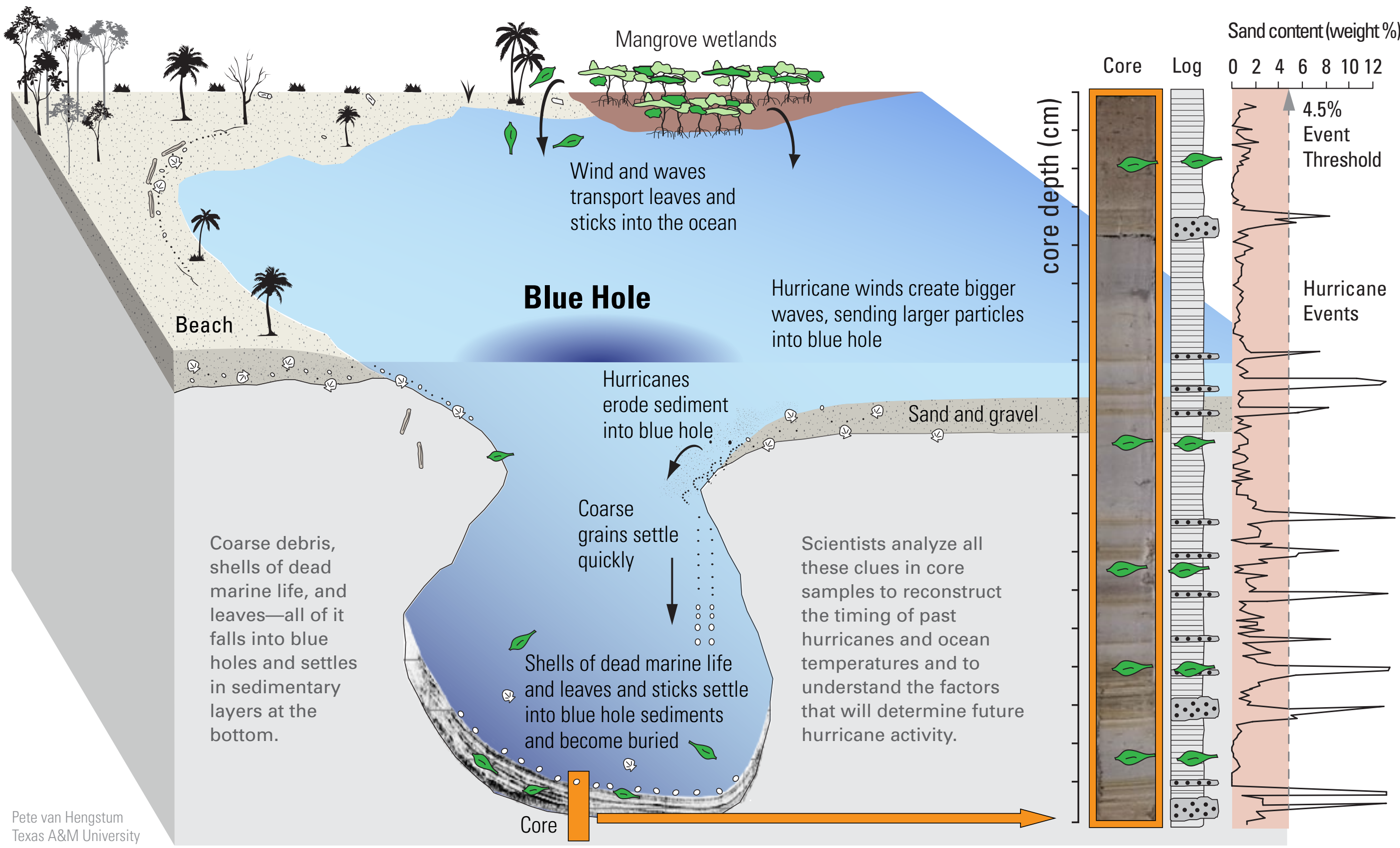
Almost every site Donnelly has sampled throughout the Atlantic region shows a record of extremely active storms throughout the first millennium A.D. "Then things shut down," he said, with an abrupt drop in hurricane frequency around the year 1400. That coincided with the beginning of a cooling period in Earth's climate history known as the Little Ice Age, which lowered Atlantic Ocean water temperatures and likely reduced the energy to fuel storms.

But this pattern doesn't hold for the hurricanes Donnelly has reconstructed for the U.S. Eastern Seaboard. "Historically, we've seen only a handful of them in the entire four-hundred-year written history of New England," he said. "But in the sixteenth century there's an interval where there's a really intense hurricane strike in New England roughly every fifteen to twenty years."

The blue-hole cores indicate a similar pattern in the Bahamas. In one particular core near the island of Andros, only two hurricanes, both Category-3 storms, appeared in the past 150 years. Yet farther down the core, in the 1500s, major storm events make landfall once per decade, nearly ten times more often.

"There's this regionality to it that's really intriguing," he said. "It's not as simple as 'turn up the knob, and everyone throughout the western Atlantic region gets more hurricanes.' "

Changing ocean temperatures, he added, may have played a major role in this uptick in East Coast hurricanes. Although most areas of the Atlantic seem to have cooled by the 1400s, the



region along the eastern U.S. became relatively warmer. Donnelly says that might explain the string of intense hurricanes that show up in blue holes and New England in the 1500s.

This East Coast ocean warming trend 500 years ago echoes a similar warming trend today. Sea surface temperatures along the Eastern Seaboard now have already passed the level they reached in the 1500s, however, and most global climate models suggest that they'll continue to climb.

"That poses the question of whether we should expect more intense hurricane strikes as climate warms today," Donnelly said. "We're just beginning to explore those relationships."

Ancient hurricane forensics

Sea-surface temperature isn't the only factor involved in major storms, Donnelly said—atmospheric conditions play a major role in both hurricane formation and intensity. The gradient of temperature between the sea surface and the air miles above it is what really gives a hurricane its deadly energy and can determine whether a weak storm will grow into a monster. If high-altitude air stays cool while the ocean surface warms, the temperature gradient increases, and a hurricane can become far more powerful as a result.

That's a point that Kerry Emanuel, a climate scientist at the Massachusetts Institute of Technology, echoed: "We'd actually expect global warming to result in fewer hurricanes overall, but more frequent high-intensity storms. And we are beginning to see that in the data," he said.

Emanuel, who has worked closely with Donnelly, notes that existing models don't yet reflect the sorts of prehistoric variations that appear in blue-hole cores. That may be because of the limitations of the models themselves. Simulating complex oscillations in air currents is a tall order mathematically and may be outside the realm of what current computer models can handle. Yet data from blue holes is still helping to improve existing models by giving real-world benchmarks. Ultimately, these will help check the models' accuracy and provide a better read on what the East Coast can expect from future storms.

"Jeff's work and the work of his colleagues provides a great and interesting challenge to modelers and theoreticians," Emanuel said. "I hope we're good enough to step up to the plate and meet that challenge."

In the meantime, Donnelly and his team continue to pull more and more details about ancient storms out of cores taken in blue holes. They're helping to build a database of past storms, and slowly educating residents of coastal regions about changing climate patterns along the eastern U.S. But the most exciting part of the job, Donnelly said, is the feeling of discovery he gets while cutting open a core for the first time.

"We're really sort of time travelers" he said enthusiastically. "We're penetrating sediments that go right through the time when Columbus is reaching North America, and into this prehistory that there was no knowledge of until we took these cores. You can go out and sample this accumulation of sediment that tells a story—a climate experiment that the Earth has already run, and that we can start to tease apart. When you look into the unknown past, it's pretty exciting business." ▲

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