

THE CHESAPEAKE BAY METEOR

A mystery, meteors and one man's quest for the truth

Story by **DIANE TENNANT**; graphics by **MICHAEL HALL**

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Graphic:

The meteor, two miles wide, crossed paths with Earth at 76,000 miles per hour, 1,266 miles per minute. Twenty-one miles per second.

It came in over the northwest horizon, a white-hot light that would have blinded had it not killed before optic nerves could signal the brain. It moved too fast for sound.

Before they saw it, before they heard it, the sharks and whales and tiny camels of prehistoric Virginia were incinerated.

The meteor blasted into the shallow sea that covered the state from Cape Henry to Richmond. It exploded with more force than the combined nuclear arsenal of today's world powers. Millions of tons of water evaporated instantly. Millions more were hurled 60 miles into the atmosphere.

The space rock, unimpeded by ocean, tore through nearly a mile of sand and sediment. It hit the bedrock granite that had been laid down 900 million years earlier and shredded it. Huge boulders, big chunks and tiny grains of solid earth were launched upward. The front end of the meteor slowed down, while the back end flew on at supersonic speeds. The bedrock, the front end, the back end compressed like an accordion, and rebounded. The bedrock fractured. Immense faults cracked open. In a maelstrom of heat and fury the meteor vaporized, leaving a crater 56 miles wide. A network of fractures spread 40 miles beyond its rim.

Friction from the air ignited rocks as they blasted out, sparking firestorms for hundreds of miles. From the sky, boulders and water recalled by gravity collapsed into the gaping crater. Like pebble rings in a pond, swells rolled out in concentric circles, headed for Greenland, Europe and the East Coast. They raced at unthinkable speeds across the ocean floor until they rose with the land and erupted. Tsunamis thousands of feet high crashed into and over the Blue Ridge Mountains.

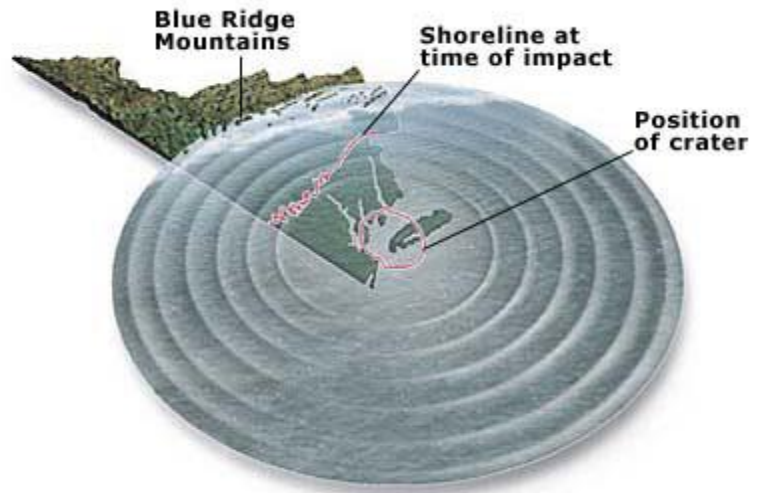
Then the water rushed back, back to the sea and the enormous empty hole, carrying dirt and trees and animals, all to be dumped into a crater as deep as the Grand Canyon.

Then it was over.

The sea, steaming and barren, flowed back over the crater. Earthquakes rumbled underwater as house-sized rocks slumped down the crater's sides. The ripples faded, and there was no one to remember that the impact had happened at all.

No one would ever know.

Not until 35 million years had passed, and David Powars dug a hole.



The hole burrowed deep into the past. What came out of it was a tube of mud 2 inches wide and more than a thousand feet long. Powars took off his glasses, looked at a sample with a magnifier, puzzled over its oddities.

Then he announced to the world that he was dead certain that his boyhood passions of astronomy and rocks had come together in one glorious megaton explosion not three hours from his mountain home.

No one believed him.

It was pretty unbelievable.

A buried crater is a marvelous thing. You can't see it, can't feel it, can't touch it, can't smell it. You will never stand on the edge and look down into it, or walk across its bottom. It is completely, totally, unequivocally lost under sand and rock and mud. Boats sail above the Chesapeake Bay crater and crabs tiptoe across it and developers build on top of it.

In a million little ways, the crater touches them. In riddles that surprise or stump them, annoy or just perplex them, the crater makes its presence known.

Something that big, that old, that cataclysmic will not lie dormant and forgotten. The crater shapes the future of Hampton Roads. For those who can read the signs, the omens are there.

The sedimentary beds of Virginia's coastal plain were laid down in orderly fashion, one on top of the other, as sea level rose and fell over time. Every geologist knew that. They even knew where the aquifers ran, like a subterranean layer cake, from the fall line to the sea.

The state's system of granting permits to drill wells into these aquifers depended on the assumption that there were layers of impenetrable clay topped by groundwater, topped by more clay, topped by another layer of water, and so on. Nine separate layers where groundwater could be tapped and pumped to the surface.

Overpumping in the 1950s and '60s drained so much water that by the mid-'70s, the state was concerned enough to begin sinking research wells throughout southeastern Virginia. Scott Bruce was on a team that, in 1983, began drilling in Newport News Park.

Bruce and his colleagues collected core samples at various depths as they drilled, to check on the permeability of different layers and to look for fossils. Paleontologists -- scientists specializing in fossil identification -- can date the sediments on the basis of what creatures were living when the bed was laid down.

But the Newport News samples frustrated them. They complained that the layers had been contaminated during collection. Older fossils lay alongside and above younger ones. Impossible to work with. The core samples were set aside, and Bruce looked eastward for his next well.

Around the same time, Powars was part of a U.S. Geological Survey team, studying subsurface layers across Virginia's coastal plain. The USGS needed hard evidence for its maps, so as the team worked its way across the plain from Fredericksburg to the Atlantic, its members also took core samples. They drilled continuous cores through all layers instead of sampling from here and there. Their deepest hole would be near Exmore, on the Eastern Shore.

Bruce's team needed a hole. Powars' team needed the core from a hole. They joined forces in 1986 and, late on a sultry August night, they pulled up a core like none they had seen before.

A core sample looks like a giant gray Tootsie Roll. To a layman, analyzing a core sample is analogous to unwrapping that Tootsie Roll and being able to see lying in your hand the sugar and cocoa and partially hydrogenated oil, right down to whether it's soybean or canola.

Rocks and soil work the same way. Each new rock or new layer of dirt or new fossil tells of climate change and evolution, to those who can read it.

This explanation requires much arm waving from Powars, standing in his home office in Stephens City before a spectacular view of the Blue Ridge, the horse pasture and teetering piles of reference books and maps. He is uniquely qualified to explain this, as he has two arms and exercises them as

he talks, which is pretty much nonstop. "I'm working on this right now," he will say. "I'll tell you about it and then I'll be quiet," which is a nice offer but a complete lie, although he says it sincerely. The core sample takes a lot of explanation.

"We do mineralogy on these cores and start seeing maybe here was renewed uplift or here was where the weather changed and we got fresh rocks eroded into the system," Powars says, rising on his toes for emphasis. "You can see, well, heck, the shoreline had to be somewhere east of the present fall line. You're getting this much wood in here, well, the shoreline was probably a delta rather than a rocky coast, things like that."

Powars had never before seen things like he saw in the Exmore core sample. The abnormalities were as easy to spot as raisins in what should be a smooth, unbroken cylinder of rubbery chocolate. The ingredients of a coastal plain, below a certain depth, were jumbled like lottery balls. The logical, geological order of the Piney Point, Nanjemoy, Marlboro, Aquia and Brightseat aquifers was no longer youngest to oldest. Some pieces of the core looked as though they had been twisted and squeezed like toothpaste.

It was the most exciting thing he had ever seen.

Powars thought he had read of this jumbled layer before. He turned to the library and the careful records Samuel Sanford and John Cederstrom had kept earlier in the century.

In 1913, Sanford published the first report on groundwater in Virginia's coastal plain. He charted the known wells on a map and drew contour lines connecting those that contained equal concentrations of salt. The result was an inland bulge around the lower Chesapeake Bay, centered around Cape Charles on the Eastern Shore.

In the 1940s, the USGS sent geologist Cederstrom to hunt for water to support the region's military buildup before World War II, given new urgency by lingering drought that had depleted surface water.

In those days, the technology to take core samples was too expensive to use often. Instead, wells were cut and chips of dirt or rock flushed out. Cederstrom sat by the wells and cataloged the layers as they came up. He noticed that the orderly sediment layers at one point became mangled. He called this strange formation the Mattaponi, a local Indian name. He also saw something else -- a low spot, perhaps a fault, where southeastern Virginia's subsurface layers seemed to drop away.

What he didn't find was good water. Where everyone expected freshwater aquifers flowing down from the west, Cederstrom found salt. At each of the 52 wells, he noted the salinity, or the amount of salt and minerals dissolved in the water. He connected the dots, too, and called the resulting contour an "inland saltwater wedge."

His work was scorned. While no one could deny that the wells were salty, no one accepted his hypothesis that the jumbled Mattaponi Formation was somehow involved, or that the structural low prevented the freshwater aquifers from flushing out the saltwater.

Sedimentary rocks didn't get mixed up; everyone knew that. Cederstrom was accused of confusing his specimens, of contaminating the samples, of being misled by the method of drilling. He lost his job at one point, was rehired, and finally retracted his published work in the 1950s, saying under pressure that he must have been wrong.

Saltwater aquifers had been known in Virginia since the Civil War. Union soldiers stationed at Fort Monroe were plagued by cisterns that dried up during long, hot summers. In 1864, the fort began drilling a well.

For five years drillers labored, dropping a weighted bit repeatedly down the shaft to chip away at rock and dirt. They finally reached water, but it was too salty to drink. Deeper they drilled, then deeper, until at 907 feet they gave up, still inexplicably drawing briny water.

No one knew why the groundwater wasn't fresh, any more than they knew why the James River took a sudden 90-degree turn to the northeast near Fort Monroe. Neither the well nor the river was acting right.

All along the East Coast, rivers flow from mountain to sea, most taking gentle inclines to the southeast until they reach the Atlantic. The James, the York and the Rappahannock rivers all flow this way until they near the coast, where they bend abruptly and turn their open mouths north and east to face the tiny village of Cape Charles. It is an anomaly. Just a few miles down the coast, the Northwest River flows as it should, southeast.

Thousands of feet below the thirsty soldiers lay the answer. The crater hungrily sucked in whatever would fill its enormous chasm. The weight of 35 million years' worth of sediment compacted the original crater debris.

No matter how much dirt went in, the crater continued to be a low spot in the floor of what would become the Chesapeake Bay.

Water flows to the lowest ground. The rivers were no exception. When the lowest ground became the sinking fill of the crater, the James, the York and the Rappahannock turned toward it, as they continue to do today.

Without the crater, the port of Hampton Roads would not exist. Without it, the shores of the world's greatest military harbor would have been cut through by the relentless drain of the James on its way to the sea.

And without it, John Cederstrom's Mattaponi Formation would never have been found, and his reputation lost.

Powers looked at the core sample in his hand and knew that Cederstrom was right. Now to prove it.



Waves of Destruction

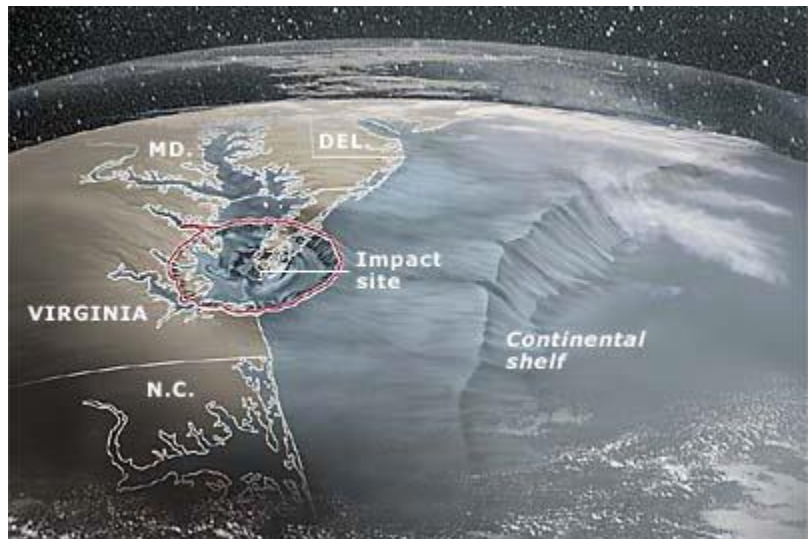
Cryptic clues from the past

Rocks from heaven have bedeviled Earthlings for centuries.

The main problem, of course, was that folks thought rocks should remain on the ground and not go jaunting about through the air.

To explain the inexplicable, some suggested that the rocks were vacuumed up by waterspouts, then dropped by thunderstorms. Others linked them to the devil.

Ernst Chladni, a German physicist, proposed in 1794 that they fell from space, prompting a colleague to complain that the theory made him feel as though he had been hit in the head by one of those rocks, and another to accuse Chladni of bringing evil to a moral world.



The debate raged on, even as rocks continued to fall around the planet in a sunny-with-occasional-showers sort of pattern. A few fell on Weston, Conn., in 1807 and two brave geologists from Yale identified them as coming from space. Thomas Jefferson joined in the ridicule, reportedly writing that he ``would rather believe that those two Yankee professors would lie than to believe that stones fell from heaven."

Only scant miles from his White House in Washington, the sixth-largest impact crater in the world silently continued altering the landscape, as it still does after 35 million years.

The Exmore drilling took months in 1986, as the U.S. Geological Survey pushed forward with its mapping and the state kept looking for water. Misfortune plagued the project: drill rods didn't fit together, the drill was pushed almost twice as deep as it was meant to go, the stored cores were attacked by fungus in a farm shed.

The idea hit Powars like a rock from heaven.

Only one person reportedly has ever been hit by a meteorite. In 1954, Annie Hodges of Sylacauga, Ala., was struck by an 8-pound stone that came through the roof of her house, smashed the radio and bounced into her leg. This event, according to impact-crater expert John S. Lewis, is the only case verified by both scientists and a medical doctor. However, in his book ``Rain of Iron and Ice," Lewis notes many records of uncertified impacts that killed, injured or just alarmed people from biblical times to the present, leading him to his own wry conclusion that, ``No one in recorded history has ever been killed by a meteorite in the presence of a meteoriticist and a medical doctor."

These historical accounts mention the Bible's Joshua, Charlemagne, various monks and the Chinese army. One of the most recent was in Peekskill, N.Y., on a Friday night in 1992. Because so many people were outside in high school football stadiums, thousands saw a fireball flash across Ohio, Pennsylvania and Virginia. The 27-pound rock landed on the trunk of a red Chevy Malibu and fell to the sidewalk where it lay, warm to the touch, in front of the car's astonished owner. All of these celestial objects made quite an impact on the witnesses and victims.

So when Powars was hit with the crater idea, it, too, left a lasting impression.

The core was in front of him, and it wasn't wrong. He didn't know why it wasn't wrong, but he knew it had not been contaminated by bad sampling. He sent a section to a colleague for fossil dating. C. Wylie Poag, a USGS senior research scientist in Woods Hole, Mass., wrote back that fossils from different geologic ages were mixed in the sample, older above younger, or side by side. Powars began to read up on the Mattaponi Formation and compare John Cederstrom's descriptions of the layer -- his lithology -- with his own.

Cederstrom thought the Mattaponi covered the entire state but was unable to prove it. Powars plotted his points and drew his own map of how widespread the Mattaponi might be. His colleagues were not amused. They argued that Powars was using flawed data to produce more flawed data. But he couldn't stop wondering what lay under the Chesapeake Bay.

Ordered to move on to other projects in his day job, he labored on the puzzle through nights, weekends and vacations. His reference books, logbooks, drawings, maps and overlays covered the floor and tables of his home office. He was convinced that the Mattaponi was not a normal formation laid down by erosion but a heap of debris possibly caused by an undersea avalanche. He began to call it a ``boulder bed," and he believed it covered nearly 2,000 square miles of subsurface Virginia. But why?

Late one night, after his wife had gone to bed, Powars straightened his aching back and said aloud, ``I wonder if anything's going to come of all this work?"

The USGS wanted to drill a core hole at Reedville on the Northern Neck, to keep going in a straight line on its original mission of defining sedimentary beds in the coastal plain. Powars badly wanted another core from the Eastern Shore.

The USGS refused, but Powars has never been one to take no for an answer. ``I don't mind being out on a limb," Powars says. ``I like working the puzzle. I'm the first one to admit I don't understand it, but I'm a good one to throw in there that you don't understand it, either. Here's this

data that suggests this or this: How do we prove one way or the other that this is what it really means?"

He waves his arms. The exercise helps him to think out loud, which helps him to compare information, reach new conclusions and think of completely new questions to research. Sentences do not seem to end when Powars talks. They go on and on and on until they merge with an unrelated thought and angle off like the James River did when it turned north and east, headed for the Eastern Shore.

Powars wanted another core hole there to test his theory that the boulder bed extended south of Exmore. Drillings in conjunction with the State Water Control Board at Fentress, the Dismal Swamp and to the north at Jenkins Bridge had produced normal layering of the sedimentary beds.

``With Fentress here and Exmore there, we knew that from here to there was a world of difference," Powars says. ``Everybody thought we had a really big fault here, a tectonic fault."

Scott Bruce of the State Water Control Board needed a research station on the Eastern Shore where he could sink wells into every known aquifer. Through such stations, the state could keep tabs on whether well pumping was depleting or contaminating the aquifers, and issue permits for pumping based on the information.

Bruce favored the southern end of the Eastern Shore because he had no research wells there, and his support -- moral and financial -- proved critical. The USGS and Water Control Board joined forces at Kiptopeke, a wildlife refuge on the tip of land where the Chesapeake Bay yawns into the open Atlantic.

It was exactly what Powars needed.

He already had well data and lithic descriptions -- detailed notes on color, texture, grain size, fossils -- from the 1800s, from the 1920s and from Cederstrom's work in the '40s. Plus, he had a big advantage over early geologists: he had cores. Those cores -- from Exmore, from Newport News and from Kiptopeke -- were showing him a widespread layer of boulders and debris. His plotting maps began to show a wall, a sudden dropoff in rocky layers. He needed to test his theory, needed a sort of ultrasound picture of what lay deep under his feet, and serendipity intervened.

Bruce had been working the Kiptopeke core hole when he saw a line of seismic survey trucks rumble up the Eastern Shore. He ran the drivers down, chatted them up and learned that they were shooting sound waves into the ground and capturing the reflections for oil companies seeking new reservoirs of petroleum and natural gas. Bruce took down names and numbers.

Powars began working the telephone.

Elusive proof to satisfy the skeptics

Story by **DIANE TENNANT**; graphics by **MICHAEL HALL**
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Coon Butte was an enigma to folks in Arizona.

Three-quarters of a mile in diameter, it had a rim about 160 feet high and dipped about 600 feet inside.

In 1891, a mineral dealer from Philadelphia went there looking for meteorites and picked up 137 iron rocks around the edges. He was pretty sure Coon Butte wasn't a volcanic crater, and he published his opinion.

One of the chief geologists from the U.S. Geological Survey came to take a look. Grove Karl Gilbert, who had been studying the moon, would soon publish a report claiming that its craters were caused by impacts, not volcanoes. He thought that Coon Butte might have a similar origin.

He was disappointed. The huge iron meteorite he expected to find in the depression was just not there. In his report, published in 1896, Gilbert wrote that the formation was volcanic, despite its lack of volcanic features. A new word was coined to describe such hidden elements: cryptovolcanic, in which ``crypto" stood for ``hidden."

He was wrong, of course.

Now it's a major tourist attraction. They call it Meteor Crater.

But David Powars avoided disappointment in Virginia. When he went looking, he saw what wasn't right before his eyes.

Powars knew the oil companies had the information he needed.

It was buried beneath layers of bureaucracy and suspicion. The companies were loath to reveal seismic surveys, fearing that competitors would profit. Powars inched his way through the maze of buck passing. ``I basically said, `I have no money, this is what I'm doing I have this core hole, I don't know what it is,' " Powars recalls. ``Everybody couldn't be nicer, but when you get down to the reality of what you're asking, it's like, `You've got to be kidding me.' "

He was desperate to know what the seismic profiles showed. Perhaps they would shed light on an intriguing new puzzle from the Kiptopeke core hole.

When Scott Bruce got his water sample, it was an undrinkable brine, 1.5 times saltier than the sea. Could the boulder bed be somehow responsible? Bruce, remembering the mixed fossils that had turned up in the well at Newport News Park, returned there to drill a continuous core sample that could not possibly be accused of contamination. Again, the fossils came up with ancient ones lying above or alongside those from younger eras.

Seeking answers, the USGS drilled a core sample in 1992 at Windmill Point on the tip of the Northern Neck and again turned up the puzzling layer. To Powars, the evidence seemed unmistakable, but the seismic information was crucial. He kept dialing.

``From '89 to '93, that's how long it took me to get that oil company data," he says now. ``Man, I called for four years, begging. People laughed at me for wasting my time."

During the years, Powars had fine-tuned his request. The oil companies were interested only in deep, deep geologic structures, so the first second of the sound wave, and the objects it reflected off, were waste material. But that was all Powars needed to show the definite outline of a crater.

``See how you're rolling along there and then, bang, it just breaks out, all those normal layers and then look at this thing coming down and changing," Powars says, tracing the seismic reflection with one finger. ``To me, this was good seismic data. I'd done enough schooling in advanced geophysics and had gotten my own books and studying that I didn't need to be a rocket scientist to interpret this stuff."

Rubble over thousands of square miles, briny water in freshwater aquifers, a seismic outline. Still, his critics didn't believe.

So again he turned to C. Wylie Poag, in Woods Hole, Mass. Poag had been working on what he thought might be an undersea impact crater at Toms Canyon, 90 miles east of Atlantic City, N.J. Poag confirmed the seismic analysis, and Powars was suddenly vindicated for years of work.

Much of it had taken place between 10 p.m. and 3 a.m., hours in which neither his family, his elderly father nor his horses required anything of him. The home office was quiet except for the dog's snoring, the papers rustling and Powars' conversations with himself. The crater was all he thought about. His dreams, in the short hours of sleep, were often of fault lines and geothermal gradients.

In 1994, Poag, Powars and Bruce cowrote an announcement article in the professional journal *Geology*. Their report made headlines around the world.

But the next year, when the USGS cut its staff, Powars, like Cederstrom before him, lost his job.

The day before he was to leave the geologic division, Powars was hired as a temporary employee in the USGS water resources section. He tried not to break stride on his crater work. His critics certainly hadn't.

For some people, a large hole in the ground was not enough to prove a prehistoric meteorite strike, even one with a megaton blast and devastating tsunamis. The ultimate proof, the evidence that without a doubt would show extraterrestrial origin, were tektites, and Powars didn't have any. Poag did.

Beneath 4,500 feet of ocean water off New Jersey, Poag and his colleagues had retrieved core samples containing tektites and shocked quartz.

Quartz develops naturally from sand under heat or pressure, but it cracks into dark lines along crystal planes when subjected to the astronomical shock of a meteorite impact. Traces of shocked quartz had turned up in Virginia core samples, but not enough to convince skeptics.

Tektites form when melted sand splatters into the air and cools into tears and spheres and dumbbells of glass as it rides atmospheric winds around the globe. Tektites had been found over 3.6 million square miles of the East Coast, each bead with the same composition, suggesting the same point of origin. But no one knew where the crater was. The North American Tektite Strewn Field stretches from New England to Texas to Cuba and Barbados. Tektites from a point off the tip of South America also may be part of the field.

Poag and his colleagues estimated that the tektites had come from a crater within a few hundred miles of their core hole. Toms Canyon was only 12 miles away, but Poag wasn't sure that it was the one. The Exmore core gave him another possibility.

In 1996, Poag sent samples of that core to experts in Austria and South Africa, who found abundant shocked quartz in the jumbled layers. Then no one could deny the evidence: The Chesapeake Bay and its surrounding land lay over an impact crater, formed by the enormous explosion of a meteorite, a comet or an asteroid, about 35 million years ago.

In recognition of their discovery, Poag, Powars and Bruce were presented in 2000 with Virginia's highest scientific honor, the Thomas Jefferson Award. It was named for a man with great interest in science, but a critic who had denied that rocks could come from outer space.

Even he would have been convinced.

The Chesapeake Bay impact crater is said to look like an upside-down sombrero, with an upturned outer rim, a trough, then a high peak in the center.

It is a complex crater, as opposed to a simple, bowl-shaped crater, because the object that created it hit hard and fast enough to melt the rock and splash it tall in the center like a skyscraper, where it hardened. A deep inner ring circles the peak like a small moat before the flat, annular trough falls away for about 25 miles on either side. The high peak, nearly a mile tall, juts up directly under the quiet town of Cape Charles on the Eastern Shore. In the late Eocene, part of the Cenozoic era, Cape Charles was ground zero.

No sign of the massive destruction is visible from the sidewalk of Bay Avenue, or indeed from anywhere in town. The deserted waterfront gazebo with the partial message "ur Own Risk" was built 35 million years too late for the warning. It looks out on a serene landscape of small dunes, tidal flats and waves not 6 inches high.

Underneath, far and deep and forgotten, is the jumbled mass of boulders and grit that was blasted out of the sea floor, then dropped back to fill a mile-deep void in the earth. Bits of the Blue Ridge Mountains lie there, too, torn from their roots by tsunamis and tumbled into the pit. The edges of

the hole crumbled and slumped in, widening the crater and adding to the loose rocky clutter that geologists call breccia (BREH-chee-uh).

But even about this there is disagreement. Some geologists insist that true breccia is sharp and angular, while the Chesapeake Bay crater contains rounded, smooth rocks. Powars, in presenting his material to the layman, has no patience with nits. ``They just want to play definition-a-go-go," he says. ``Just call them breccias. The bottom line is, this is a pile of debris. I just call it `crater fill.' "

And what it filled was an area the size of Delaware, smack dab on top of Virginia.

The mystery solved led only to a bigger puzzle, with more pieces missing. What was in the breccia? How thick was it? And, more importantly, what was it doing to the groundwater?

Bruce had achieved his goal at Kiptopeke, sinking test wells into aquifers at various depths. But the well in the breccia produced undrinkable water. At depths of only 1,330 feet, the groundwater was 1.3 times saltier than the sea.

For the State Water Control Board, the results were troubling. With Hampton Roads and the Eastern Shore already scrambling for water, and with developers lined up to build houses and schools and industry, water was the biggest, and most basic, need.

Did the nine aquifers on state groundwater maps flow into the crater or around it? Was the water any good? In places like Mathews County, which lie entirely above the crater, would pumping draw salt water into fresh? Would a well in the breccia be reliable or peter out?

And what did it mean for cities on the crater rim, like Norfolk and Virginia Beach? A well in Norfolk, at Moores Bridges, has already produced water 1.4 times saltier than the sea. Was it a fluke? Or a problem?

The seismic profiles proved more revealing than anyone expected. The prehistoric impact had possibly fractured bedrock seven miles deep into the Earth and as far as 84 miles in diameter. The crater was affecting the land from the shoreline to West Point, and the ocean floor halfway to the continental shelf.

Intrigued by the science and worried by the economics, four different agencies drew up a five-year plan to study the Chesapeake Bay impact crater. The work, at about \$1 million a year, began in October 1999 with the drilling of a core hole at NASA Langley Research Center, which lay inside the crater's outer rim.

NASA has sent satellites and orbiters into space to study impact craters, but now it could look in its own back yard for information. The USGS and the Water Control Board (by this time, renamed the Virginia Department of Environmental Quality) would examine geology and aquifers. And the Hampton Roads Planning District Commission would hope for an answer to the big question: Is the region's water supply in trouble?

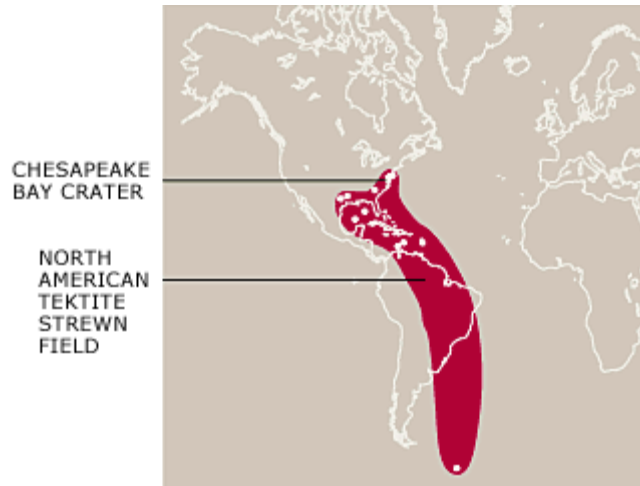
Finally, the scientific community was as engaged as Powars had been all along.

Graphic: Tektites and the strewn field

Graphic by **MICHAEL HALL**

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Tektites are tiny beads of glass, formed when melted rocks and sand spatter into the air and cool into teardrop, sphere and dumbbell shapes. Atmospheric winds can carry them around the globe.



White dots on the map above indicate where tektites have been found over 3.6 million square miles, an area called the North American Tektite Strewn Field. The tektites are similar in composition, indicating they came from the same crater, in the Chesapeake Bay, although some people believe the South American tektites are from a Russian crater that also formed about 35 million years ago.



Graphics:

(Salty) water, water everywhere

The water we drink, wash cars with, sprinkle lawns with, play in; the water that drives new industry and subdivisions and jobs; the water that grows cotton and soybeans and peanuts and cattle; the water that drizzles out in long, hot, drought-filled summers; this water most often comes from under the ground.

It slips through layer cakes of rock and sand and clay. It flows, if the creeping movement of groundwater can be called a flow, through pores in the earth. Clay has the most, but those pores are the tiniest and some carry a static charge that repels the water molecules. So the water moves, instead, through sand.

Aquifers are not, as some people believe, underground pools of water. They are layers of sediment that allow water to collect between the grains. Imagine a water balloon filled first with sand, then with water.

The sediment layers collected over millions of years. As ice ages came and went, drawing the sea level down, then melting it back up, the shoreline traveled from Richmond to Virginia Beach, then 50 miles farther east than it is today, then back to Virginia Beach, then back to Richmond.

It did this numerous times, until there were nine different sandy layers where water could pool into aquifers, separated by nine different clay layers that restricted water from moving up or down. The only way to remove it was through wells, deep vertical pipes that punctured the layers of clay and sipped from the layers of sand.

The impact wrecked all that. The aquifers, where they cross the outer rim of the crater, are broken. Geologists call this "truncated." It means they are, for practical purposes, gone. The sandy aquifer beds were blasted into the atmosphere. Did the groundwater from undisturbed parts of the aquifers flow on into the crater? Or did it find the jumbled breccia too tough to penetrate? No one knows, but it appears that the groundwater may be taking the path of least resistance around the north and south rims, leaving little pressure to flush out the salty water trapped in the crater.

The question, Scott Bruce says, is how much water can you get out of a well that's sunk into the crater. The answer, so far, is not much. And what has come out is a brine.



David Powars pulls out a color-coded map showing salt levels in various wells along the East Coast. "Once you're in the blue, that's as salty as seawater," he explains. "You can see this big freshwater plume up here in the north, way deep. That's from the big glaciers; you had so much fresh water melted it completely flushed out the system. You can go off the shore in New Jersey, and there's fresh water below the ocean. That's pretty neat.

"Then you come down here," he says, pointing to southeastern Virginia, "and get a couple different stories. See how much this blue line comes up? To 18,000

milligrams per liter, which is pretty bad. You're not drinkin' that water. And here it's getting shallower. I thought this was just too cool, to show bull's-eye, bang, the saltwater keeps coming up. So at less than 1,000 feet in here, where the crater is, you find the salinity's high."

Four aquifers formed across the top of the crater, laid down on the breccia over millions of years. But five existed before the meteorite arrived. When it hit, it shattered them, and two of those -- the Upper and Middle Potomacs -- are the ones most used by public water systems in Hampton Roads.

More than 1.5 million people rely on public water supplies here, and the population is growing. Of the 13 cities and counties that provide public water locally, six depend solely on groundwater. Four blend groundwater with surface water. Another 327 private water systems and 320 noncommunity wells (such as schools and malls) also draw groundwater.

Public utilities have to figure out how the crater is affecting the water, said Scott Emry, geologist with the Hampton Roads Planning District Commission. "We believe that everything within that crater will be salty. All this is so brand new that we're still going through the analysis phase and scratching our heads and saying, 'What does that mean?'"

To stop the itch, commission members chipped in money to study the long-buried impact crater. This year's contribution is \$88,250, matched dollar for dollar by the U.S. Geological Survey.

Part of the work includes looking for an isotope in water squeezed from the core samples, a type of chloride that might tell scientists the origin of the salt and even how long the water has been in the

crater. Both are important in understanding where the salt may end up as a result of pumping the aquifers.

Powars points to a different line of blue on the chart. ``That's super bad. At 2,500 feet. Look at that. Off the chart. That's worse than the worst water almost known. That's the one at Moores Bridges in Norfolk.

``That's been known as a real wicked, super nasty, nasty bad water. I mean, whew, really bad stuff. Nobody's been able to explain that, but we're starting to get there now."

An aquifer is under pressure, both from the soil and rock around it, and from the water pushing in from the west. When a pipe is sunk into one, the pressure causes the water in it to actually rise higher than the level of the aquifer.

The state has a rule: Pumping must never cause the water in the pipe to drop below 80 percent of its original level. Reduced pressure in one aquifer may encourage water from other aquifers to jump ship, or even suction saltwater in sea beds back toward the land. If the pressure drops, the water balloon will start to deflate, and the land on top of it will begin to sink.

Even before the crater was discovered, the state had identified two areas believed to have ``significant stress" on their water supplies. One is the Eastern Groundwater Management Area, from Virginia Beach to Richmond, by way of the Peninsula, and down I-95 to the North Carolina line. The other is the Eastern Shore.

By requiring permits for large-volume groundwater pumping in those areas, the state hopes to keep the aquifers from running dry. But Hampton Roads uses more than 60 million gallons of groundwater a day, not counting agricultural wells and private wells.

``From a study done over on the Eastern Shore, before this crater was ever studied, they figured out, the USGS did, trying to figure out water resources back in the '60s, you go down below 300 feet, you're probably not going to find fresh water," Powars says. ``And now that we've done some deeper tests over there, you can forget it. I've long said the Eastern Shore of Virginia, you're in trouble. Well, the answer is desalinate."

Several cities and counties already have begun that process. Gloucester County is building a plant to take the salt out of drinking water. Chesapeake, Suffolk and Newport News are already on line. James City County is considering one. The question is what this pumping, from wells just outside the crater rim, will do to salt levels in the groundwater. The rim might act as a barrier. It might not. And other factors may be at play.

``What boggles everybody's mind is that all of the models say everything should have quieted down, cooled down, there shouldn't be any remnant heat (from the crater explosion)," Powars says. ``But when you crack the earth seven miles down . . . you might easily have awoken an old lava zone there. Somehow, if you add heat into this thing, the temperature could maybe do some weird things with salinity and stuff. We've played with this a little bit, but it's pretty much been behind closed doors. We haven't told anybody in public, because this is arm-waving stuff."

And then there are the earthquakes.

How the crater affects local rivers

Graphic by **MICHAEL HALL**

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Water flows to the lowest ground. When the lowest ground became the sinking fill of the impact crater, the James, the Rappahannock and the York rivers changed their lower courses to flow toward it.

Rumblings from the Earth

Solid ground is a misnomer.

The Earth is a shifting planet, continents drifting over liquid lava, rocks refusing to lie still under the soil.

Where they slip and grind together, the planet shivers, sometimes dramatically, like in Turkey and California and Seattle.

Smaller earthquakes have been recorded around Hampton Roads since 1775. Doubtless, they also occurred earlier, but no one knew how to measure them or to tell where they originated.

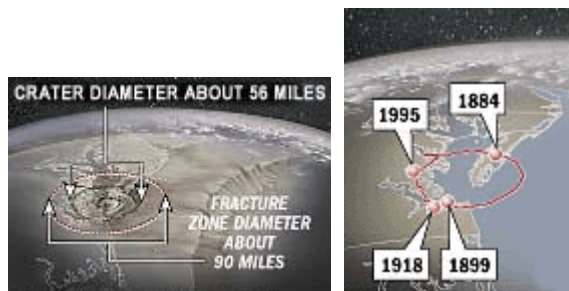
Now they do.

The meteorite hit with tremendous energy, and that energy had to go someplace. It went into heat and light, into melting the rocks and blasting a hole. And what was left over rippled through the ground itself, creating swells and waves and, finally, cracks.

The cracks, or faults, broke in concentric circles around the crater, intersected by other faults that began at the center and radiated outward until they lay in the delicate symmetry of a spider web -- rings within rings, connected with spokes -- over southeastern Virginia.

The fractured earth never healed. Small movements attest to that.

In York River State Park, in 1995, the temblor felt like a heavy truck rumbling past. Some people didn't even notice. At 2.6 on the Richter scale, the earthquake was too small to do any damage but was felt at Camp Peary and detected on instruments in Blacksburg and Goochland County.



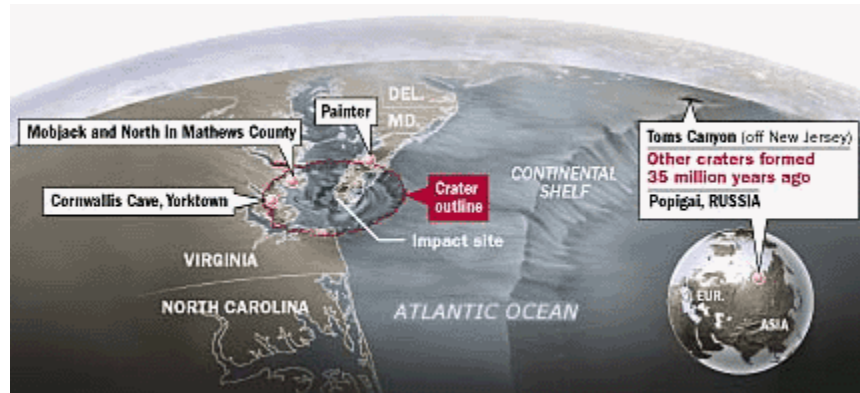
Three other earthquakes with known points of origin were plotted by Gerald Johnson, a geology professor recently retired from the College of William and Mary. They were felt in Painter, on the Eastern Shore, in 1884; in Norfolk in 1899; and Chesapeake in 1918. Their strength is unknown, but one thing is certain: They plot on a large circle that overlies the rim of the buried crater.

York River State Park is not within the crater. But it does lie over an area where rock was cracked by shock waves from the meteorite impact. If a line were drawn connecting the ends of tidal rivers like the Chickahominy and Elizabeth and Piankatank, it would form a rough circle around the crater, on the boundary of this fracture zone.

“We think that where we've been defining the outer rim is not really the outer rim,” David Powars says. “I mean it is, it's an escarpment, but there's still all sorts of things messed up and we may have some real jumbled-up piles of sediment outside the escarpment for quite a ways in what we've been calling this outer fracture zone. That's why, instead of coming up with a roughly 90-kilometer crater, we come up with a 135-kilometer (90-mile) structure.”

The seismic reflections taken by the oil companies show small faults webbing through the rock from the crater almost to the bottom of the Bay. They look misleadingly small on the roll of paper spread out on Powars' couch.

“At that depth, even seeing that little teeny bit, that's a couple hundred feet,” he says. “That's what's really scary. So when you see one that really steps up, like we saw in the raw data, there might be 700 feet of offset there. This is still nothing compared to California. They have faults tens of thousands of feet offset. California's a mess.”



The U.S. Geological Survey ran its own seismic study last summer, from the NASA Langley Research Center to the north edge of the James River. Approximately every 5 feet, a small charge was detonated about 2 feet underground. Powars has just received the results and, when analyzed, the reflections should give more precise information about fault lines and the fracture zone.

The researchers hope to run another seismic line later this year, perhaps across Mathews County from the core hole drilled this spring near the village of North. Powars would love to see it cross a strange ridge called the Suffolk Scarp.

Along Va. 14, just after leaving the town of Gloucester Court House on the way to Mathews, the Mount Zion United Methodist Church perches on the scarp about 85 feet above sea level. The scarp juts abruptly from flat soybean fields only 12 feet in elevation and extends just a short distance before sinking back down.

The William and Mary professor had puzzled over the ridge since the 1960s. He had mapped the layers of earth that were exposed in the cliffs of Cornwallis Cave in Yorktown and examined the fossil shells of different ages that lay side by side in a borrow pit at Mobjack. It was a splendid riddle, but he could not explain it. The layers of dirt, instead of sloping seaward, tilted back toward land. That they had tilted this way for eons was obvious to Johnson: A fairy shrimp had tunneled into the sediment millions of years before, a shrimp that digs a vertical burrow. The fairy shrimp's hole was not tilted; the sediments around it were.

“I gave a fantastic paper in 1968, described everything beautifully, but couldn't explain it,” Johnson says now. “Now things that were unexplainable are explainable. We've discovered that, really, this area of Virginia is not the most stable, it's moving and things are changing, and it's all because of what took place 35 million years ago.”

The ridge along Va. 14 apparently mimics the outer rim of the crater far below it. Another ridge northwest of U.S. 13 near Painter, where the earthquake was, also appears to follow the crater rim. The Big Bethel Scarp and the Diamond Springs Scarp, low terraces in Hampton and Virginia Beach, also are on the crater rim, buried several thousand feet below but still influencing the surface of the volatile land.

``Anywhere from I-64 to Big Bethel Road behind the landfill, right in there seems to be some good faulting," Powars says. ``The other interesting point from that seismic data was when we got outside (the crater), we were well over near the James River, the basement was noticeably higher up.

``I'm pushing very hard for the project to study more of this aspect. It may give an idea of what may happen in the future as we continue to pump on the south side of the crater. You've got this real high salinity in here. It could be that it's just a natural phenomenon; it's never been flushed because there's a natural barrier here with the basement up high."

Much of Hampton Roads and even beyond is settling slowly over faults and cracks and the loose breccia filling the crater.

Picture the cover over a swimming pool. Every time it rains, water puddles in the center. The



weight of the puddle makes the cover sink lower, making room for more water to collect, which makes the cover sink lower, which makes more room, and so on.

Scientists concerned about global warming and melting polar ice set up a network of monitors to track the rise in relative sea level around the world: in other words, how fast the water is rising in relation to the land. The monitor in Hampton Roads, in the lower James River near its sharp northeast turn, shows one of the highest relative rises in sea level of anywhere on Earth. Melting ice is not the sole cause. More likely, the

land is sinking.

But the crater's presence is not all negative. Scientist C. Wylie Poag has suggested that the Chesapeake Bay crater, like 35 others around the world, may contain mineral deposits such as oil or gas or gold or nickel, valued at billions of dollars.

He says that crystalline basement rocks, like those under the crater, usually form enormous melt sheets when impacted, up to 2,500 cubic miles in size. Mineral deposits in such a melt sheet could be valuable, but the core hole needed to sample them, perhaps 5,000 feet deep, would cost at least half a million dollars.

It is possible that the Chesapeake Bay crater was formed by an object that broke apart before impact, or that several celestial objects hit Earth around the same time, leaving craters strewn around the world. Two other craters -- Toms Canyon off New Jersey and Popigai in Russia -- also are around 35 million years old.

``We're constantly thinking . . . it should be a mile or two-mile diameter impactor," Powars says. ``I'm thinking that our impactor may be smaller. There's a theory that says this large an impactor ought to cause global extinction. Well, it may be that this one wasn't that big, or that it broke up. I still think this may be one of a whole bunch, like a comet like Shoemaker-Levy that broke up."

One of the discoverers of that comet, which smashed into Jupiter in 1994, was Eugene Shoemaker. Shortly before his death, Shoemaker looked at the Exmore cores and said they were unquestionably of extraterrestrial formation, the stamp of approval from the world's most renowned impact scientist.

In 1997, Scott Bruce placed a call to John Cederstrom, long since retired from the USGS and living in southwest Virginia. You were right, Bruce told him. There really is a jumbled layer of rock and sediment, what you called the Mattaponi Formation back in the 1940s. We think it was caused by a meteorite, or a comet, or an asteroid, because there's a crater there, too.

He was thrilled, Bruce recalled. Just a few months later, Cederstrom died, absolved, after 50 years, of bad science and bad image and bad work.

Target: Earth

Story by **DIANE TENNANT**; graphics by **MICHAEL HALL**
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The Nemesis theory says that we are not alone.

A small red or brown dwarf star may travel an elongated path that brings it around our sun about every 26 million years. This star would travel a path that takes it 2.4 light years away -- far, far beyond Pluto -- then back to within half a light year, still a little past Pluto.

The orbit would take it through the Oort cloud, a region outside our solar system filled with rocks and icy balls, thought to give birth to comets. As it passes through, the star's gravitational pull might bump comets loose, setting them on a collision course with Earth.

Although this star never has been observed, the outer planets sometimes stray from their predicted orbits, as though tugged by an invisible string. And spurts of comet or meteorite impacts over millions of years have coincided with Nemesis' closest approach.

Early reptiles and marine life were wiped out 198 million years ago. The dinosaurs died around 65 million years ago. The Chesapeake Bay crater was formed about 35 million years ago.

If Nemesis is out there, we're due.

"How deep are you?" David Powars shouts over the noise of the truck-mounted drill rig.

``Six-" the driller pauses for mental arithmetic. ``Ninety-five."

``Oooooooh!" Powars exclaims, rubbing his hands together, and not just for warmth. The core hole is 695 feet deep. The top of the tortured rubble that fills the crater -- jagged granite, shocked quartz, plasticized clay -- is nearly in reach.

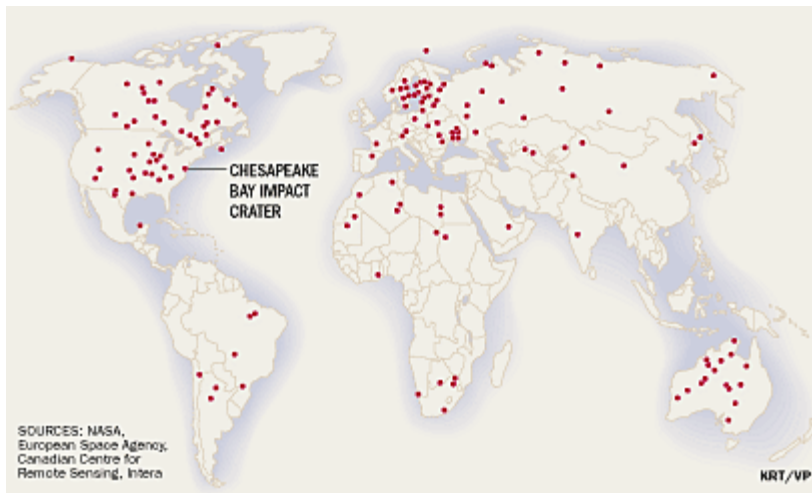
``One of my greatest joys is watching that come up," Powars exclaims, waving his arms and rising on his toes for emphasis. He bounds away as though the drill has just penetrated a high-voltage electrical line.

On the first day of spring, March 21, 2001, the U.S. Geological Survey begins its second year of crater research, drilling a core hole into a commuter parking lot on Va. 14 in Mathews County. A second core hole is now being drilled in the county, this one on the edge of the Bay in Shadow.

Powars looks around for a razor blade, settles for a 12-inch knife, trims a sliver of mud off a core sample, misplaces his glasses, shoots a whole roll of film, reloads his camera, shoots another roll and inhales. Scott Bruce looks up from his logbooks and field notes, thoughtfully watches the performance for a minute, then silently rescues the glasses from boot-soled oblivion.

They have worked together for 15 years. The scene is repeated endlessly, but it never gets old: Another core comes out of the hole, slimy with drilling mud, is cradled in plastic tubing, handled with surgical care to avoid contamination with younger dirt. It is washed, measured, scratched, microscoped, labeled, photographed, sliced and stored.

Every sample makes its case for what Powars humbly calls the greatest catastrophe that ever occurred on the East Coast since the origin of the planet.



Discover magazine, in

October, listed 20 ways that the Earth might end. Topping the list was collision with a giant comet, asteroid or meteor.

“I think, eventually, just because it's a matter of time, there will be a large massive object that will hit the earth,” says Joel Levine, atmospheric scientist at NASA's Langley Research Center.

USGS scientist C. Wylie Poag estimates that one house-sized object per month disintegrates in Earth's upper atmosphere. Estimates are that between one and a dozen marble-sized or smaller meteorites land in Virginia each year, where they masquerade as ordinary rocks.

Others are large enough to attract attention. In 1991, '92 and '94, brilliant fireballs over Hampton Roads prompted many frantic calls to police about burning airliners. In 1972, a large fireball was filmed skimming the western United States and Canada. It rose into the air until it disappeared, presumably escaping Earth's gravity.

Others don't. Something exploded in the air above Tunguska, Siberia, in 1908, leaving trees flattened for several miles around. In January 2000, a 220-ton meteorite shattered over British Columbia, splattering a frozen lake with fragments.

No one was injured.

But large craters on Earth, on the moon, on Mars and on asteroids prove that impacts do occur, and some folks are starting to worry. About five years ago, NASA started searching the skies for objects like asteroids and comets that could threaten Earth, Levine says. Astronomers find them, catalog them and assess the risk of collision. By early May, 307 potentially hazardous asteroids had been identified, but none poses significant danger.

“I think that if anything is coming toward us that's big enough to cause damage, we'll know about it several days in advance,” he says.

Although a few days sounds like precious short notice, that may be all that's needed for a well-prepared world to detonate a nuclear warhead close enough to the invader to nudge it away from Earth without shattering it into millions of pummeling meteorites.

If we see it coming.

“Well, it depends on how big it is, it depends on what direction it's coming from,” Levine says.

“If, for example, it's coming from the sun's direction, you won't be able to detect it because the sun is too bright. But if it came from the opposite direction, you could see it at night.”

If the Chesapeake Bay meteorite hit today, in exactly the same location, it would destroy most of the major East Coast cities, says Poag in his book, “Chesapeake Invader.”

The millions of people who live there would be dead in a matter of minutes.

Assuming that doesn't happen in the next three years, research will continue on the existing crater.

It's important, Levine says, to understand the effect on the Earth as a whole.

``The atmosphere affects the ocean, the ocean affects the atmosphere, the atmosphere is affected by land, life is affected by the atmosphere, the ocean is affected by land -- they're all interconnected," he says.

The meteorite, or comet, or asteroid seared its path through the sea with heat and light born of friction. Faster than instantly, seawater exploded into steam.

Sunlight broke apart the airborne water molecules, creating hydrogen atoms and hydroxyl radicals, which combine one oxygen and one hydrogen atom. It converted salt -- sodium chloride -- into chlorine. All are efficient destroyers of ozone.

In a matter of minutes or days, a hole had opened in Earth's protective ozone layer, larger than the one over Antarctica today. No one knows how long it lasted.

``I think this will be some world-class science coming out of this, and world-class science is going to impact not only the people in this community but the people in the entire world," Levine says. ``We're going to learn more about impact phenomena from this crater than from any other crater."

Powars -- a biologist in college, a geologist in career -- has been studying physics of late.

``I'm finding out that when the thing hits, all of a sudden it can start moving the target rocks as fast as the impactor was traveling," he says, his right hand smacking the palm of his left. ``The rock it hits actually starts traveling that fast or faster, that's how they can escape. When you get these rocks that you find on our planet from Mars or from the moon, they actually have escape velocity. It hits and then it gets blown out of the crater and can fly right out of gravity. Zoop! I'm getting more and more impressed as I get into the mechanics of stuff.

``Now, instead of just describing that we had a hole, we're starting to get into the placements, the timing and the mechanics. We're at the beginning of this."

He has been busy this spring, giving talks at the Lunar and Planetary Conference, the Geological Society of America, the Carnegie Institute of Washington, the Virginia Air and Space Museum. The seismic reflections from the NASA core hole have just been processed and are ready for him to study. The Mathews cores are coming up. The work must be repeated in different locations. Time is in short supply.

He takes a minute of it to look over his paperwork on the Kiptopeke core hole. ``It was pretty cool that the story really built on (John) Cederstrom's stuff," he says.

``They'd talked him out of his interpretations in the '50s and got him to rescind on them: No, it wasn't so deep and this is contaminated and you can't use this information. That was one of the main arguments against me, that I was using data that you couldn't count on. It was not poor quality data. Cederstrom was talked out of it, but I kept saying no, I have a trend here."

Cederstrom lost his job because of it and was rehired. Powars lost his job, too, and was rehired as a temporary. That job is about to end, and he may soon be out of work again. He is not bitter.

``Oh, yeah, it was worth it," he says. ``It was worth it because I like doing puzzles as much as anything, and this is a puzzle still unfolding.

``Who cares who thought what when, to be honest. I care about what are we going to do with it now, and what are we going to do tomorrow with it? I'd rather spend the little bit of time I have on the planet working another puzzle."

So he stands in the mud on a cold spring morning in a parking lot near Mathews, watching, waiting, hoping for the drill bit to penetrate the scar of an ancient crater, a ravaged pit where death appeared 35 million years ago, on the day the sky fell and the heavens rained fire and brimstone.