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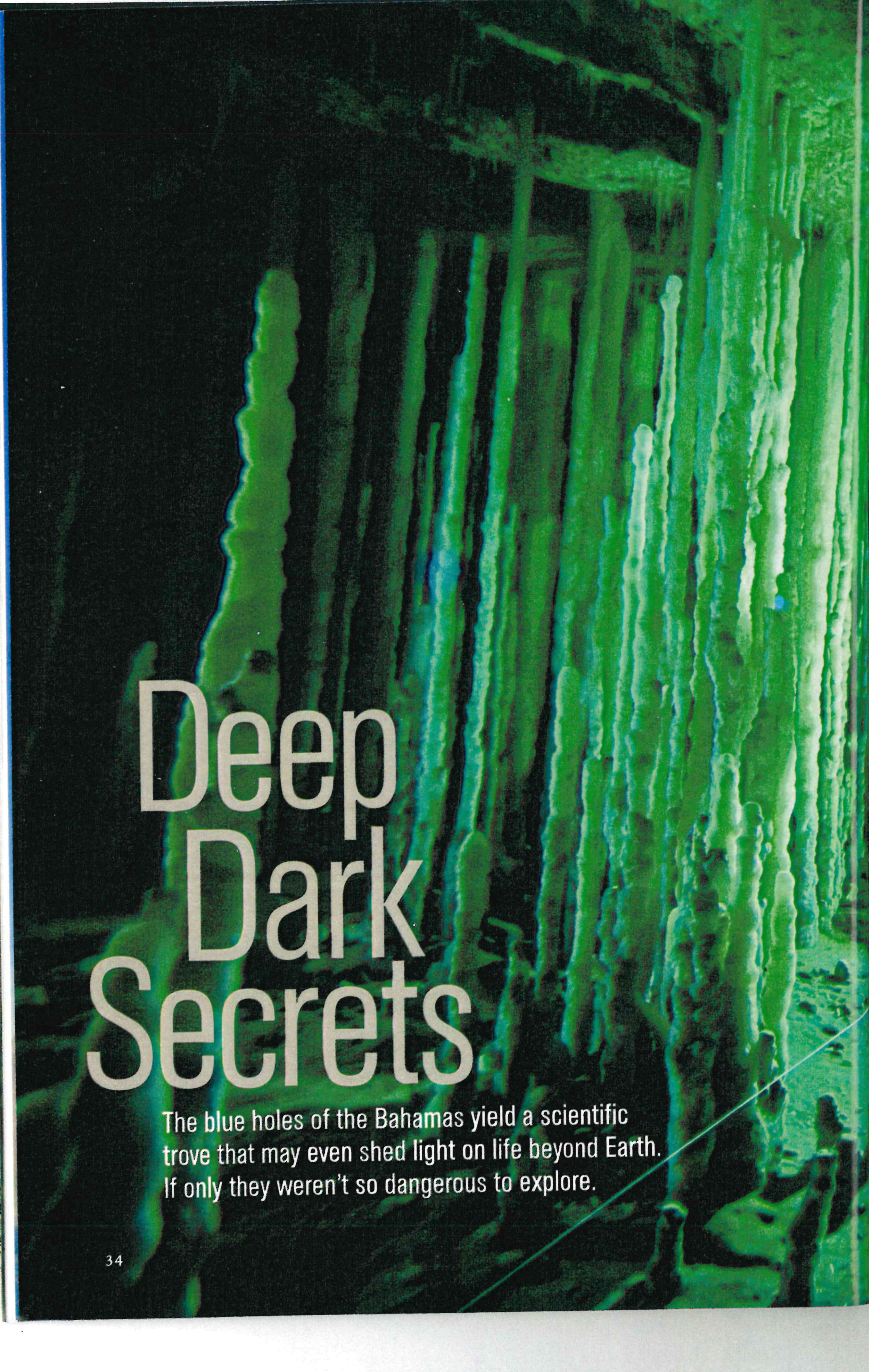
NATIONAL GEOGRAPHIC

Bahamas Blue Holes

DIVE INTO BEAUTY, DANGER, AND DISCOVERY

PULLOUT POSTER
Inside the Blue Holes

A NEW EAST-WEST RAILROAD 54 RESTORING TRIBAL LANDS 80
HEAVEN FOR RHINOS 98 EGYPT'S ANCIENT WHALES 118



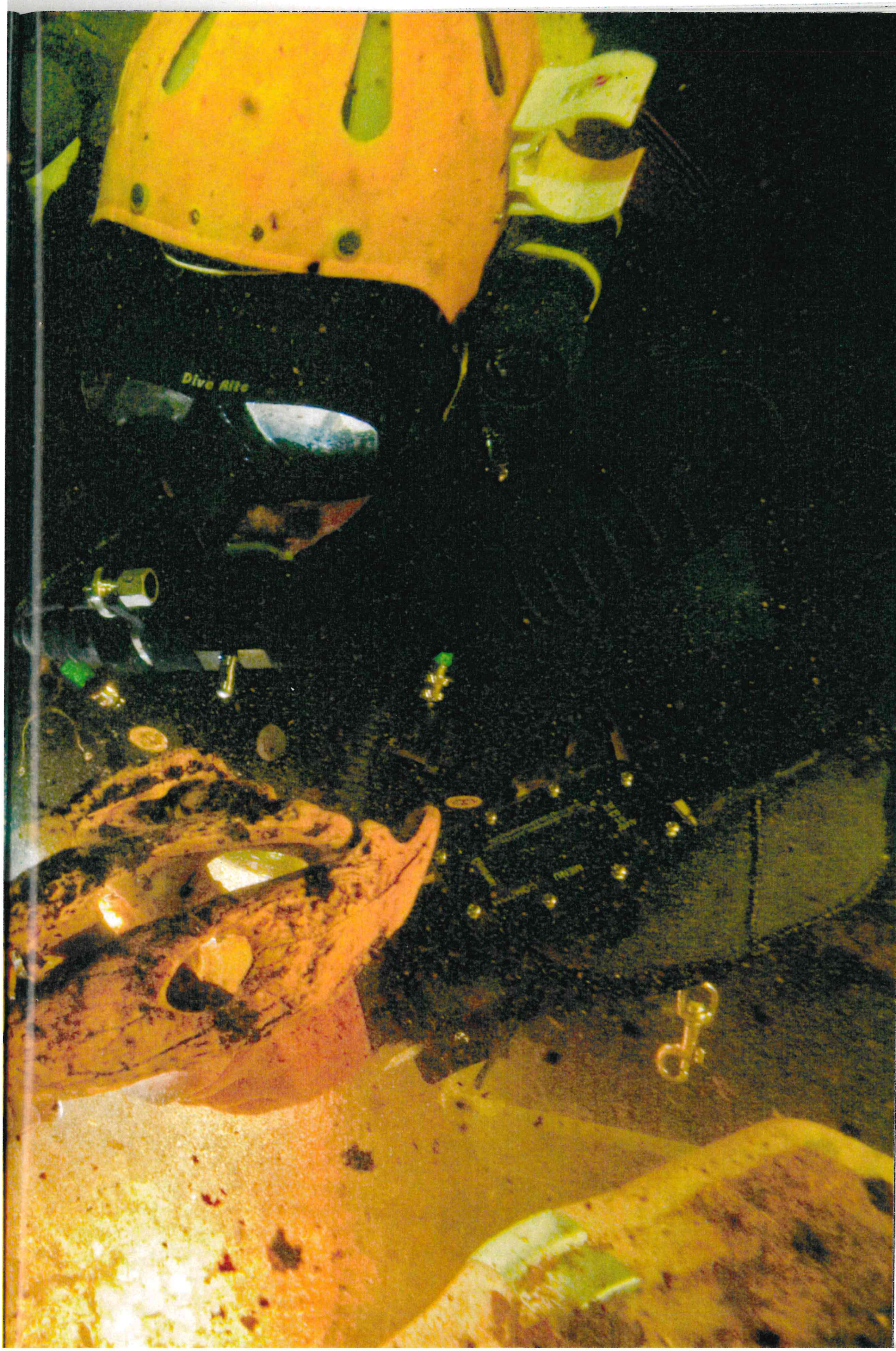
Deep Dark Secrets

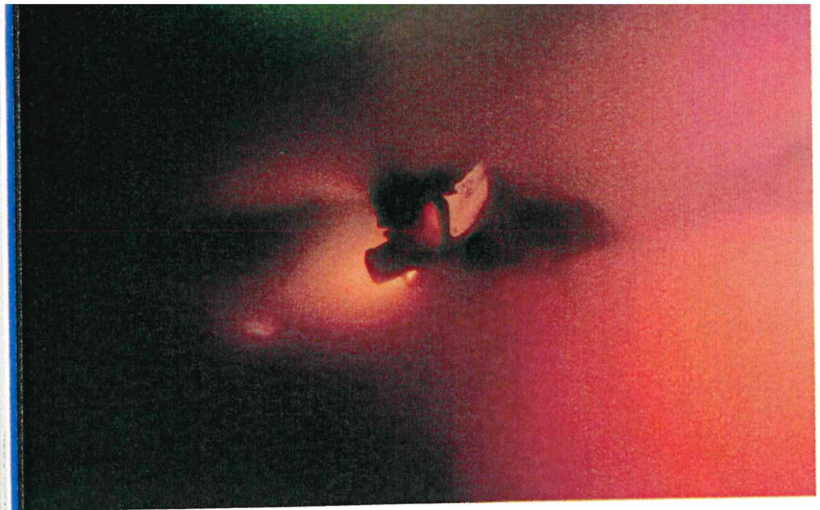
The blue holes of the Bahamas yield a scientific trove that may even shed light on life beyond Earth. If only they weren't so dangerous to explore.

Following the guideline her life depends on, a diver threads the needle through a stalagmite forest in Dan's Cave on Abaco Island. A single, misplaced fin kick can shatter mineral formations tens of thousands of years old.

Bacteria color the water at a depth of 30 to 36 feet in Sawmill Sink on Abaco. Here and in a colorless layer below, poisonous hydrogen sulfide gas is present. Divers move through it with all deliberate speed.

Veteran cave diver Brian Kakuk lifts a more than 3,000-year-old Cuban crocodile skull—an animal no longer found in the Bahamas—from sediment in Sawmill Sink. Nearly oxygen free, blue holes preserve bones intact.


Dive Rite



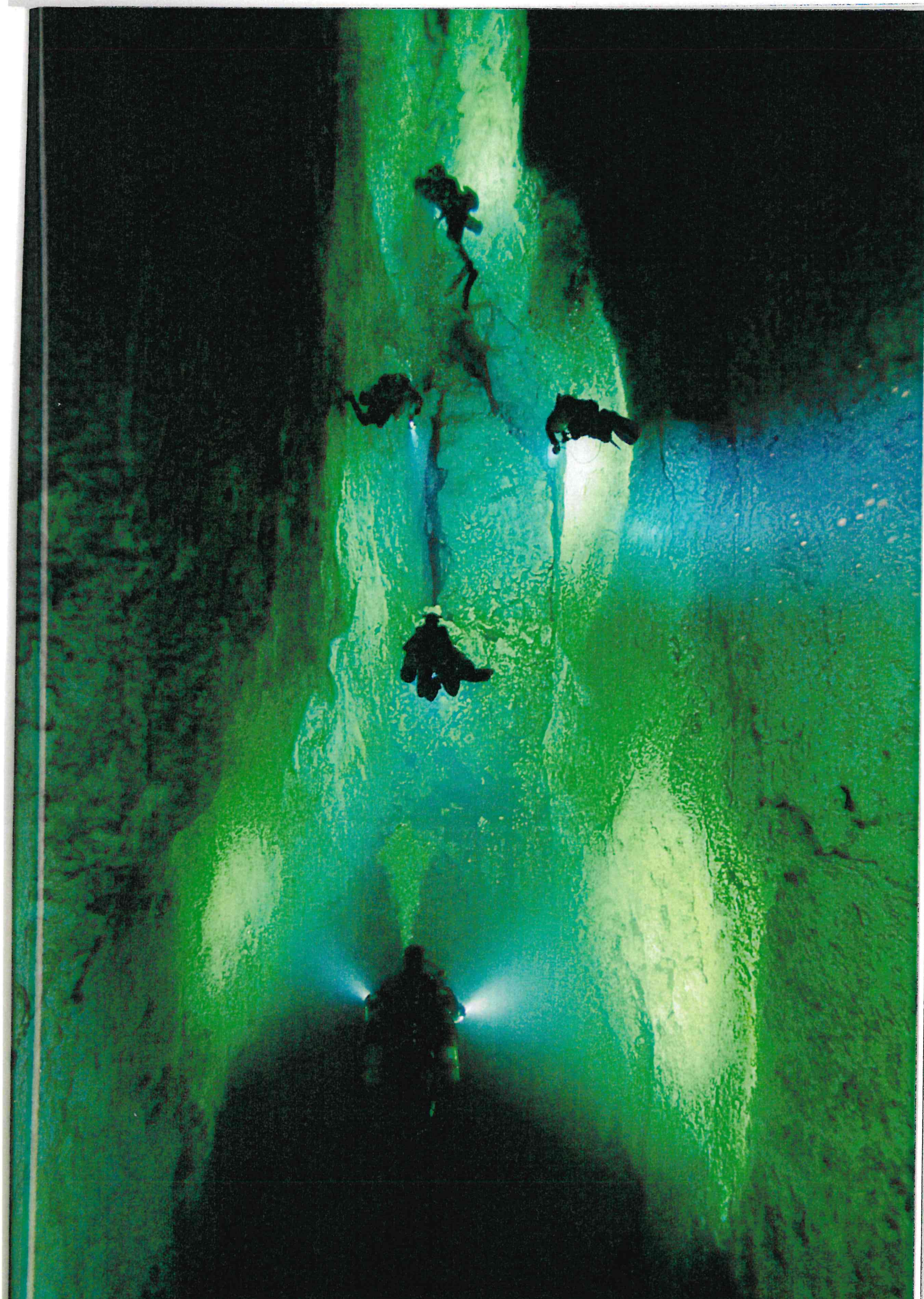
BY ANDREW TODHUNTER   PHOTOGRAPHS BY WES C. SKILES

We sink into Stargate, sweeping the void with our dive lights. Fifty feet from the surface looms a pale haze, less smoky than fibrous, like a silvery net of faint, swirling cobwebs hovering motionless in the darkness. It's a layer of hydrogen sulfide, a toxic gas created by bacterial colonies and decaying organic matter. Divers entering the gas may experience itching skin, tingling, or dizziness; some smell rotten eggs as it penetrates their skin and metabolizes through their lungs. The gas density in Stargate is relatively low, but I'm struck by a wave of nausea as we descend. I glance at my guide, Brian Kakuk—one of the world's foremost cave divers. He appears unfazed. My head begins to throb; clearly, I'm unusually sensitive to the toxin. In the epic poem *Beowulf*, "dim serpent shapes" in the depths guard the lake of Grendel and his mother, shielding their lair. The otherworldly mist in Stargate appears to serve a similar role—a poisonous curtain that protects the deeper reaches of the cave.

Offshore flooded caves, so-called ocean blue holes, are extensions of the sea, subject to the same heavy tides and host to many of the same species found in the surrounding waters. Inland blue holes, however, are unlike any other environment on Earth, thanks largely to their geology and water chemistry. In these flooded caves, such as Stargate on Andros Island, the reduced tidal flow results in a sharp stratification of water chemistry. A thin lens of fresh water—supplied by rainfall—lies atop a denser layer of salt water. The freshwater lens acts as a lid, isolating the salt water from atmospheric oxygen and inhibiting bacteria from causing organic matter to decay. Bacteria in the zone just below the fresh water survive by exploiting sulfate (one of the salts in the water), generating hydrogen sulfide as a by-product. Known on land as swamp or sewer gas, hydrogen sulfide in higher doses can cause delirium and death.

As living laboratories, inland blue holes are the scientific equivalent of Tut's tomb. From a diver's perspective, they're on par with Everest or K2, requiring highly specialized training, equipment, and experience. Even more than high-altitude mountaineers, cave divers work under tremendous time pressure. When something goes wrong, if they don't solve the problem and make it back to the cave entrance before their gas runs out, they're doomed.

In Stargate, a blue hole on Andros Island, divers illuminate North Passage (right). In Sawmill Sink (above), expedition leader and anthropologist Kenny Broad descends through the bacterial layer on an exploratory dive.



"All of a sudden, it's got you," says photographer Wes Skiles of the "insanely dangerous" vortex in Chimney Blue Hole (left) off Grand Bahama. Like a giant bathtub drain, it sucks down millions of gallons when the tide comes in. "It's like going over a waterfall—there's no escape." Keeping his distance, a diver sets up equipment to measure the whirlpool's flow rate. From a protected cove on Long Island, Dean's Blue Hole (above)—Earth's deepest known underwater cave—plunges more than 600 feet into darkness.

Until now, only a handful of scientists have ventured into blue holes, but in the summer and fall of 2009, a multidisciplinary cave-diving and scientific team spent two months studying them on Andros, Abaco, and five other Bahamian islands. Funded by the National Geographic Society in collaboration with the National Museum of the Bahamas, headed by Keith Tinker, the Bahamas Blue Hole Expedition was conceived by Kenny Broad, a veteran cave explorer and an anthropologist at the University of Miami. Under Broad's wisecracking, driven leadership, with Brian Kakuk as dive safety officer and preeminent cave explorer Wes Skiles shooting film and stills, team members made around 150 dives in dozens of blue holes. They gathered data that promise to deepen our understanding of everything from geology and water chemistry to biology, paleontology, archaeology, and even astrobiology—the study of life in the universe.

They worked with urgency. At the current rate of sea-level rise (possibly several feet over the next century), many inland caves will flood with seawater in the coming decades, disrupting their delicate chemistry and destroying the very conditions that make them so valuable to science. Meanwhile, blue holes are often used as dumping grounds, polluting the islands' primary source of natural fresh water. "Look at the damage we're doing to highly visible and beautiful resources like redwoods, whales, and coral reefs," Broad says. For all its importance, he explains, the invisibility of the underground world leaves it off the conservation priority list. So the expedition also made it a goal to publicize the importance of blue holes and the threats they face.

WE INSTINCTIVELY ASSOCIATE LIFE with oxygen, but living things existed on Earth for more than a billion years in the absence of the one gas divers can't last minutes without. Ironically, the oxygen revolution came about through the rise of bacteria that created oxygen as a waste product. Jenn Macalady, an astrobiologist at Pennsylvania State University's Department of Geosciences, is studying the water chemistry of Bahamian blue holes to understand the conditions most similar to the earliest, oxygen-free environments that supported life. She's especially interested in the period from about four billion years ago—when life first appeared on Earth—to what scientists call the oxygen revolution, some 2.5 billion years ago. By investigating bacteria that thrive in the anoxic waters of blue holes, she can postulate what may exist in the oxygen-free, liquid-water environments of distant planets and moons. "The universe is made of the same elements," Macalady says, "and habitable planets are likely to share many of the same characteristics, like a temperature range conducive to life and the presence of water." Many astrobiologists believe such conditions may exist in pockets of liquid water deep beneath the surface of Mars or in a sea under the frozen crust of Jupiter's moon Europa—to say nothing of far distant worlds potentially much more like our own.

Macalady doesn't dive, but she's an active dry caver who hauls tanks, coils ropes, and chats with young Bahamians about cave slime and the possibility of life in the universe. At her direction, divers take water, bacteria, and hydrogen sulfide samples at depths ranging from the surface to 270 feet. Most of her studies—including DNA testing, bacterial culturing, and the search for molecular fossils—must wait until she gets back to the equipment in her lab. But hydrogen sulfide is too unstable to transport, so

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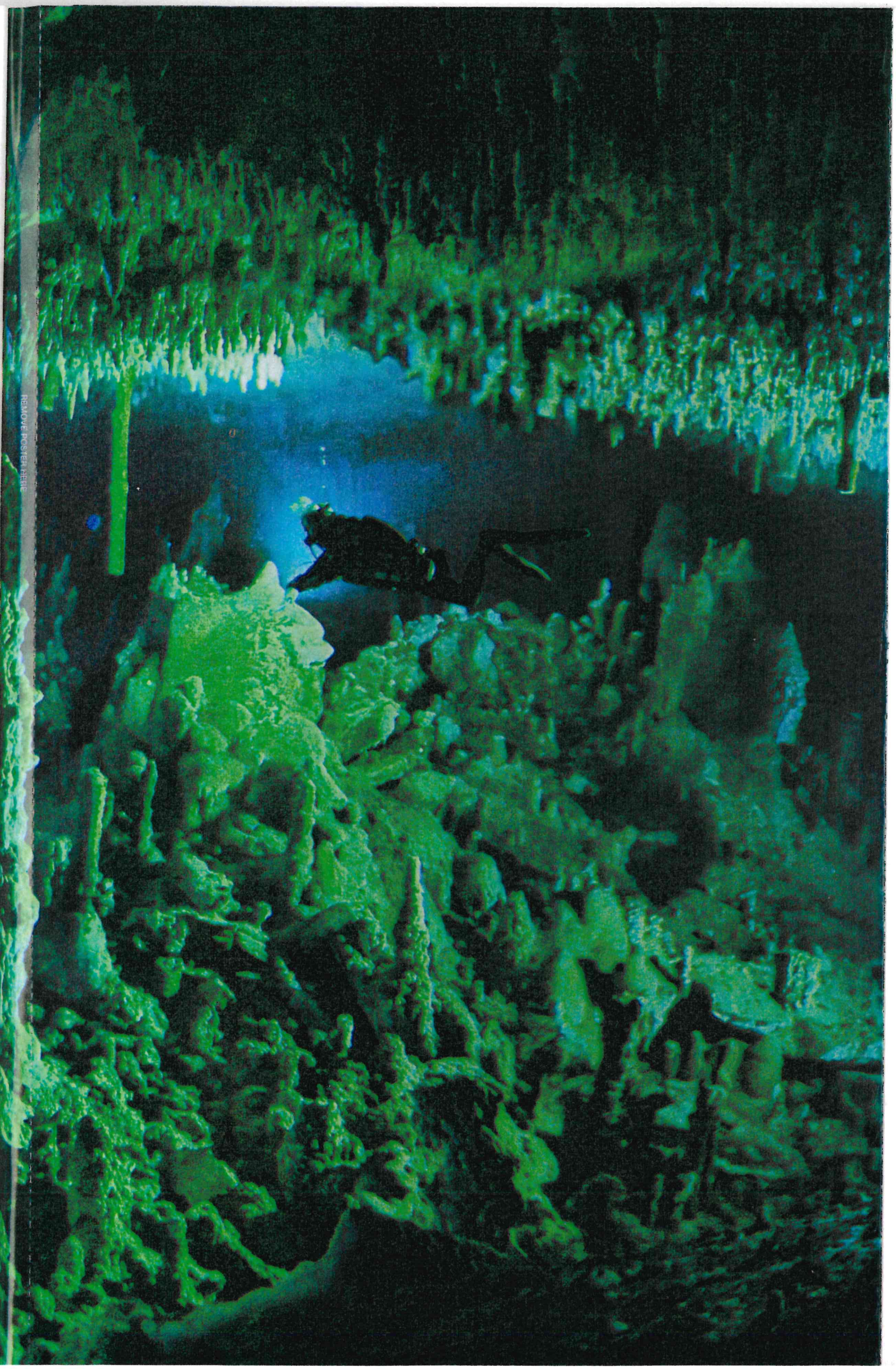
Andrew Todhunter's latest book is the award-winning A Meal Observed. *Explorer Wes Skiles is a pioneer in underwater cave photography.*

VICKIE TAYLOR, INTERNATIONAL MAPPING; NGM MAPS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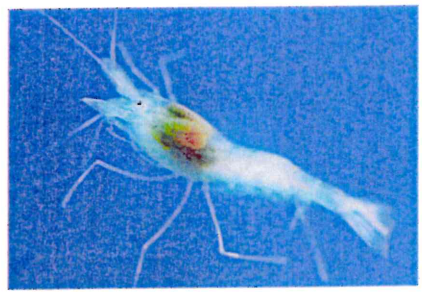
she analyzes water samples for gas levels with a portable spectrophotometer at the dive site. By comparing sulfide densities with water depth, she's learning where different species of bacteria are likely to concentrate in a given blue hole and which mechanisms they use to survive. She is aided by Nikita Shiel-Rolle, a Bahamian cave diver and marine science graduate student at the University of Miami. Stargate's entrance lies on land that's been in her family for generations.

"To give an idea of just how unique each hole is," Macalady says, "we analyzed the DNA of microbes from five inland blue holes and didn't find any shared species." She is continually surprised by the variety of ways cave organisms harvest energy. "Some of these organisms use tricks we used to think were chemically impossible," she says. "If we can understand precisely how these microbes are making a living, we know what to look for on oxygen-free worlds."



In lightless blue holes, animals like this inch-long *Agostocaris* cave shrimp don't need surface pigmentation. Only part of the shrimp's digestive system has color.

As living laboratories, blue holes are the scientific equivalent of Tut's tomb. From a diver's perspective, they're on par with Everest or K2.

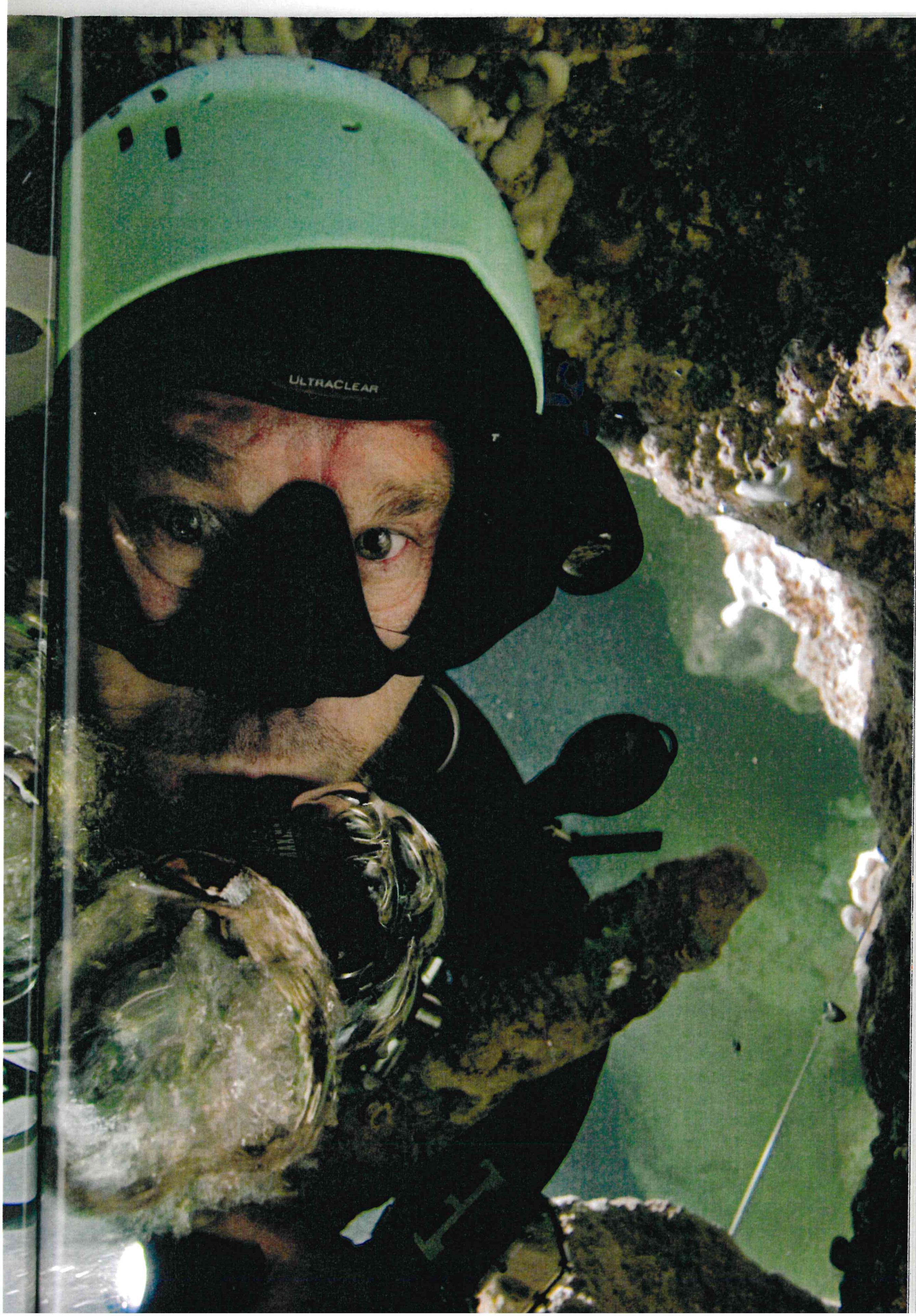
As Kakuk and I emerge from the hydrogen sulfide into the black water below, my nausea and headache quickly pass. I'm relieved not to have to put into practice the suggested method for vomiting underwater, to say nothing of the impact my breakfast—a biological mushroom cloud—would have on the fragile environment. We descend slowly along the cave's east wall until a triangular portal appears in our lights: the entrance to a 2,500-foot-long tunnel known as South Passage.

Stargate consists of a central shaft some 340 feet deep, with passages extending north and south. Kakuk has explored North Passage about 1,300 feet out from the central shaft, edging ever closer to the next blue hole to the north, and he's pushed even farther into South Passage. Of the more than one thousand blue holes believed to be in the Bahamas, less than 20 percent have been probed, and Kakuk estimates that three-quarters of those offer passages never seen before. The great age of Bahamian blue hole exploration lies ahead.

The entry to South Passage is decorated by spectacular calcite formations, or speleothems, from drapery (thin, curtain-like formations) and straws (fine, cylindrical deposits like soda straws) to the more familiar stalactites and stalagmites. (Remember, stalac*tites* need to cling *tightly* to the ceiling above.) They built up during ice ages, when the sea level dropped dramatically, leaving the caves dry. For Peter Swart, professor of marine geology and geophysics at the University of Miami, speleothems hold a priceless record of climate change in every year of their growth—at the inexorable rate of one to five centimeters every thousand years. By studying speleothems in detail, Swart, Broad, and Amy Clement, a climate modeler at the University of Miami, will gain valuable information about sudden climate shifts of the past. These include prolonged storms that blew Saharan dust across the Atlantic from Africa thousands of years ago, leaving high concentrations of iron in the stalagmites and red stripes visible in the sediment of cave walls. Information

Archaeologist Michael Pateman lifts a centuries-old Lucayan Indian skull (above) from a gridded site 110 feet down in Sanctuary Blue Hole on Andros Island. Brian Kakuk (left, both) has an arsenal of offbeat tools for gathering samples. His turkey baster collects red dust blown from the Sahara in ancient times, and the inflatable lift bag brings a stalagmite to the surface to be studied for evidence of abrupt climate changes in the past.

His air bubbles forced down by the current in a blue hole on Abaco, Kenny Broad fights to the surface, a stalagmite under his arm. Divers must bring extra breathing gas when they'll have to struggle against a siphoning tide.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from speleothems will shed light on today's rapid warming and the associated rise of sea level. "The better we understand how the natural climate system works," Swart says, "the better we can understand the nature and degree of our own impact."

AT KAKUK'S DIRECTION, I tie off our safety reel to the line at the entrance of South Passage and follow him inside. In the play of our lights, the natural geometry of the corridor is breathtaking. Above soars a vaulted, triangular ceiling; below, a floor of impenetrable darkness. There is an eerie quality of intention—the vaulted corridor seems more designed than randomly occurring—and I'm reminded simultaneously of the outer walls of Mycenae and the gallery in Khufu's Great Pyramid. Covering my light with my palm, I hover and watch Kakuk's single lamp move steadily forward as the walls' steep angles come into view. I had expected a measure of anxiety in such an alien environment, but for all its unearthly surrealism, this motionless, lightless place is profoundly calming. For a moment I relax completely, releasing an attenuated breath and swinging my light upward through the swarm of ascending bubbles.

Two hundred lateral feet into South Passage, Kakuk collects a water sample for Macalady in a plastic tube. He points out a fish with a shimmering, translucent tail that flickers like a candle flame—a *Lucifuga*, about five inches long. Like most life-forms in these lightless depths, the fish is blind. Then Kakuk directs my attention to a *Barbouria* shrimp, a reddish, two-inch crustacean with long, bowed antennae for sensing prey in the darkness. Minutes later, he pauses and shines his headlamp on his fingertip—his signal for the presence of the tiniest creatures. It's an ostracod, a crustacean no bigger than a sesame seed, its brilliant pink interior sheathed in a transparent, clamlike shell. High on its round body, a pair of antennae flutter like fairy wings, propelling the animal through the water.

Kakuk is known for his ability to spot things most other divers—including trained scientists—never see. During his 21-year career diving in blue holes, he has discovered more than a dozen new animal species, four of which expedition scientist Tom Iliffe, himself an expert cave explorer and a professor of marine biology at Texas A&M University, has named after Kakuk. In recent decades Iliffe and other scientists have discovered an astonishing abundance of previously unknown organisms in these and other flooded caves around the world: more than 300 new species, 75 new genera, nine new families, three new orders, and a new class, Remipedia, first documented in 1981 in the Bahamas.

Most cave-adapted species are crustaceans, and many, like the remipedes, are "living fossils"—live species closely resembling those preserved in the fossil record. Iliffe says that the greatest percentage of saltwater cave species come from blue holes in the Bahamas, including 18 of the 24 known species of remipedes. Remipedes emerged 300 million years ago and give scientists a rare look at life in the Carboniferous period—tens of millions of years before dinosaurs appeared. With slender, segmented bodies less than two inches long and usually colorless and blind, remipedes are, nonetheless, at the top of the food chain in their habitats, using hollow, venom-injecting fangs to kill shrimp and other crustaceans.

AS WE FIN DEEPER into South Passage, the only sound is the rhythmic hiss of our regulators and the rumble of our exhaled breaths. Kakuk occasionally traces a broad circle with his light on the passage wall, signaling the question, "OK?" I return the signal as an affirmative response. I've known Kakuk less than two months, but my life depends on his judgment, and his, to some degree, on mine.

In cave diving, redundancy is critical. If one of my lights goes out, I have three in reserve. Our gas supplies—in this case oxygen-enriched nitrox, a combination of oxygen and nitrogen—are backed up with two independent tanks and regulator systems. As long as we follow the rule of thirds (one-third of your total gas going in, one-third coming out, and one-third in reserve

Society Grant This project was funded in part by your National Geographic Society membership.

for emergencies), we should always have enough to get home—even if one of our tanks or regulators fails. That's assuming we don't lose our guideline. In the labyrinth of passages, separation from the line can be fatal. In my training, Kakuk had spun me around with my eyes closed and towed me away from the line to simulate disorientation. Groping blindly and using my safety reel to search in a spoke pattern, it took me 12 interminable minutes to find the line. One of Kakuk's students was so traumatized by this drill that he bloodied his hands clawing for the line along a cavern roof. For his part, Kakuk has logged some 3,000 cave dives without serious injury. Given the risks, the lighthearted mood of Broad's team belied this fact: Combined, these divers have participated in dozens of body recoveries from submerged caves.

Some 500 feet into South Passage, we reach the end of the main line, tied off to a bollard of calcite at a depth of 130 feet. Here the tunnel narrows and plunges to below 230 feet. On previous dives, Kakuk had extended the line 2,000 feet farther, but at my level of experience, we've come as far as he'll allow. We check our air—the first of our thirds is nearly depleted—and turn for home.

At the portal separating South Passage from Stargate's central shaft, Kakuk covers his lights and stops. The faint green of daylight in the shaft beyond is just strong enough to cast the walls of the passage entry into silhouette. I allow my limbs to hang freely, my body rising and sinking almost imperceptibly with each breath. Time appears to stop. I'd like to float here for hours, weightless and relaxed, suspended in the void, all thoughts draining from my mind.

The remipede is a "living fossil" nearly unchanged for 300 million years. It kills its prey, primarily other crustaceans such as cave shrimps, with venom-injecting fangs.

The lighthearted mood of Broad's team belied this fact: Combined, these divers have participated in dozens of body recoveries from submerged caves.

ASCENDING SLOWLY to a depth of 60 feet, we pause at a sloping ledge directly below the cave mouth. In the middle of the ledge is a long trough packed with silt. Kakuk spotted this promising feature on an earlier dive and now reaches into the mud. He gropes gently back and forth and—so quickly it seems miraculous—extracts a long bone the color of mahogany: a human femur. Two smaller bones follow. Then he extends his arm deeper, working the silt, and draws out the domed pate of a human skull. Although lacking a lower jaw, the yellowed skull has molars on both sides and a single front tooth. The forehead slopes dramatically, a sign that its owner was a member of the native Lucayan tribe that thrived in the Bahamas from the sixth through the 15th centuries. To create a sloping brow, Lucayans bound boards to their children's foreheads. Some archaeologists think the practice was intended to make the front of the skull better able to withstand blows in battle; others believe it was purely aesthetic.

Kakuk hands me the skull. Silt and leaf fragments clog the eye sockets and nasal cavity. I try to imagine—from the brow, eye sockets, and cheekbones alone—how this individual appeared in life. In its breadth and solidity, the skull strikes me as distinctly male. Was he a warrior? A shaman? I return the precious object to Kakuk, who reburies it in the silt to await later study.

In 1991 Rob Palmer (the cave-diving pioneer who named Stargate) and his team discovered and excavated 17 sets of Lucayan remains from a cave on Andros called Sanctuary: 11 adult males, five adult females, and a child. On the 2009 expedition, Michael Pateman, an archaeologist and cave diver with the National Museum of the Bahamas, recovered the remains of two more Lucayans. He will carbon-date and study the bones (and those Kakuk found on our dive), seeking information about the age, sex, stature, diet, and life stresses of these individuals as well as how they died.

"One of the things we know about the Lucayans is that they were tremendous divers," Pateman tells me. "They were sought out by the Spaniards to dive for pearls. And we've found evidence of deep diving on some of the skulls—over time, in response to the pressure, bone builds up around the ears." As with so much in the scientific study of blue holes, Pateman's work has barely begun. Foremost on his mind is the question: How and why did Lucayans end up in blue holes? He suspects that the submerged caves were burial sites, but the discovery of a bound Lucayan body in a dry cave on one island suggests other, more violent practices. Were they murder victims? Were they victims of feuding, warfare, or religious sacrifice?

Lucayan bones are just part of the tapestry of blue holes, says Nancy Albury, project coordinator at the National Museum of the Bahamas, whose passion for blue holes centers on the animal remains they contain—the remarkably preserved fossils and bones of crocodiles, tortoises, bats, owls, beetles, and other species that thrived in the Bahamas before the Lucayan occupation. "In some blue holes," Albury says, "we've found complete skeletons and soft tissues preserved on tortoise shells thousands of years old. Leaves still have their structure and pigments, and insect wings are still iridescent blue and green." As expedition paleontologist Dave Steadman explains, the anoxic, sheltered environments of blue holes are perfect for preserving organic material. Were it not for blue holes, Steadman says, much of the fossil record for Bahamian animals going back thousands of years would not exist.

ONE OF THE REWARDS of the expedition's multidisciplinary approach is the constant exchange of ideas and enthusiasm among scientists with wholly different backgrounds. Swart's work on speleothems will shed light on ancient climates, which in turn may explain how and when some Bahamian animal species went extinct—Steadman's and Albury's domain. Pateman's work on human remains may reveal as yet unknown connections between Lucayans and animal bones found in blue holes. Without the unique geologic structure of the inland blue holes—deep, dark, sheltered, with little tidal flow—specialized bacteria studied by Macalady would never have gained a foothold. And if the bacteria hadn't created an anoxic environment, many of Iliffe's species wouldn't have flourished in the caves and much of the biological evidence would have vanished. As Broad puts it, "I can think of no other environment on Earth that is so challenging to explore and gives us back so much scientifically."

Rising slowly toward the surface, Kakuk and I pass again through the veils of hydrogen sulfide to our decompression bottles: tanks of pure oxygen hanging from a length of plastic piping at a depth of 20 feet. We switch to these tanks and hover, breathing easily. Time and oxygen at this depth will eliminate the nitrogen that has built up in our bloodstreams during the dive, preventing decompression sickness—the bends—that in extreme cases can cripple or kill a diver. After 18 minutes of decompression and a total dive time of 65 minutes, we emerge into the warm Bahamian air. Even here, as I float on my back for a moment, resting on its liquid skin, Stargate feels like a benign and alien world. □

Kenny Broad and Brian Kakuk surface at dusk after multiple dives in Sawmill Sink, where they collected bacteria samples and fossils. "It's an alien world down there," says Broad, "that keeps pushing us beyond our dreams."