BODY OF EVIDENCE

FORENSIC ANTHROPOLOGIST AMY MUNDORFF HAS BEEN IDENTIFYING HUMAN REMAINS FOR YEARS. NOW HER GOAL IS TO MAKE THE SEARCH FOR THE MISSING SAFER AND MORE SUCCESSFUL.

BY HANNAH HOAG

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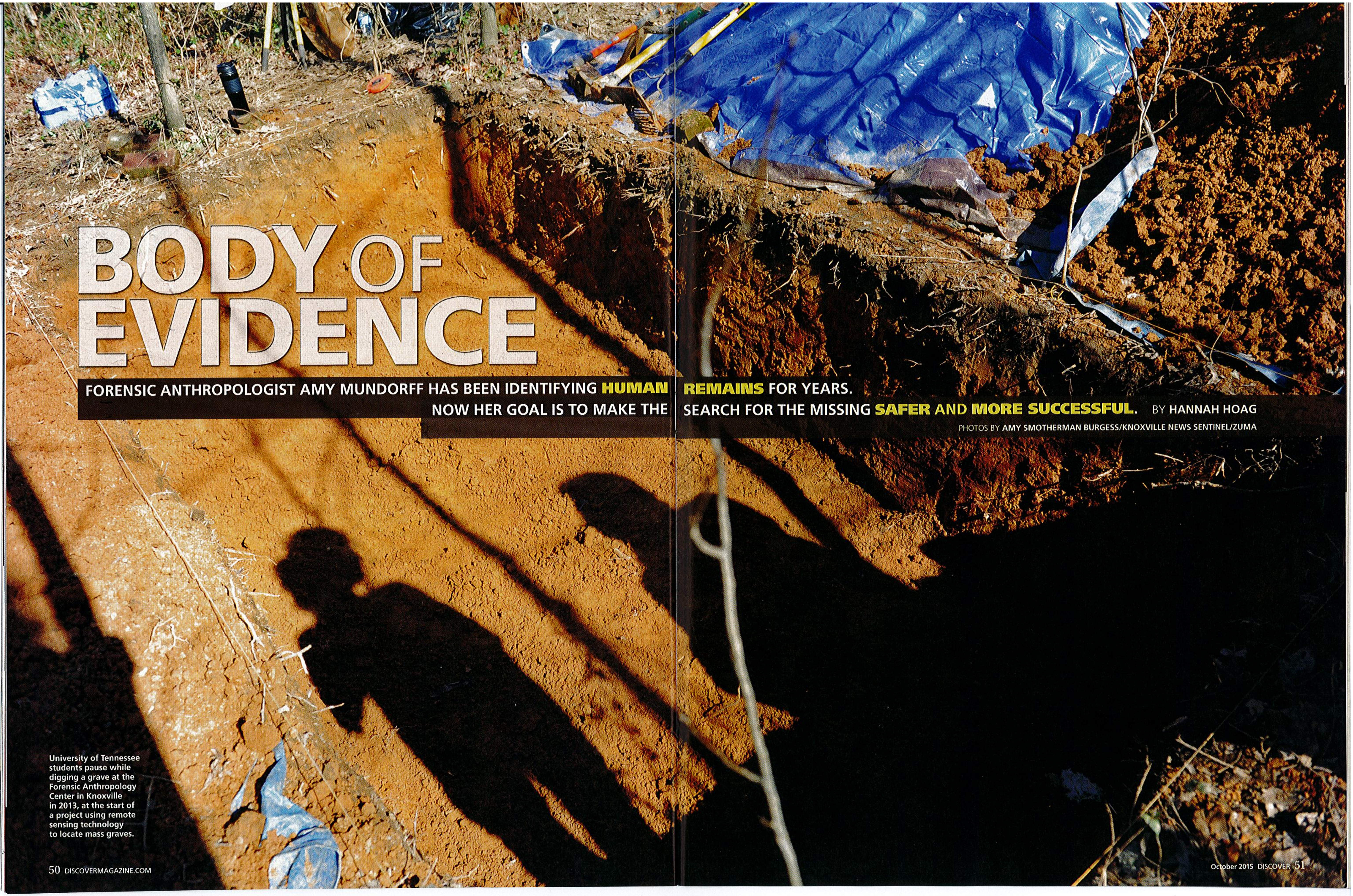


University of Tennessee students pause while digging a grave at the Forensic Anthropology Center in Knoxville in 2013, at the start of a project using remote sensing technology to locate mass graves.

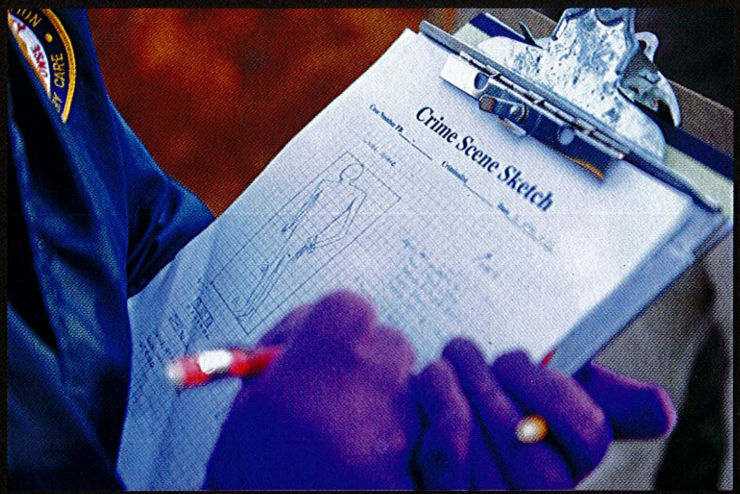
ONE MORNING IN JULY 2005, Amy Mundorff rode into the Bosnian countryside, tagging along with a team from the International Commission on Missing Persons. The roads wound past forests, farmland and villages. The group stopped near a field in a hilly area on the outskirts of a village to meet an informant. From the gestures and the translator's comments, Mundorff understood that the ground beneath the field might hold bodies.

The war in Bosnia-Herzegovina had ended 10 years earlier, but thousands of people remained missing, many presumed buried in hidden graves scattered across the country. Mundorff, a forensic anthropologist, wanted to learn how the team excavated and exhumed graves, and then sorted and identified co-mingled human remains — her area of expertise.

Backhoes scraped away the topsoil, peeling back the earth inches at a time. "They just dug and dug and dug," recalls Mundorff. Once in a while, the machinery operators would stop and call over an investigator. "It was never anything human. There were roots, animals bones, rocks … but there were no graves," says Mundorff. By the end of the day, the entire hillside had been dug up, and the team found nothing.

Witness and survivor testimonies remain the most reliable way to locate hidden graves, but the approach is not foolproof. Many of the conflicts under investigation occurred years ago. Elderly witnesses may have fading memories that offer incomplete or incorrect accounts of atrocities. Sometimes the geography of a place changes. Roads get rerouted, forests are cleared, and the edges of villages expand.

Mundorff knew from her own searches for buried murder victims in the United States that investigators often fail to locate hidden graves, but she didn't expect it to be so difficult in Bosnia-Herzegovina: The country is smaller than Louisiana, and the whereabouts of 8,000 people remain unknown.



Forensic anthropologist Amy Mundorff measures the depth of a grave as the remote sensing research project gets underway (far left). Grad student Katie Corcoran records gravesite info (above), and Dawnie Steadman, director of the Forensic Anthropology Center, assists in the process (left). Ten human bodies were donated for the multiyear project.

Mundorff didn't expect it to be so difficult to locate hidden graves in Bosnia-Herzegovina. It's smaller than Louisiana, and 8,000 people are missing.

"Even if we didn't find that one grave, I thought we would find something because … where are they?" says Mundorff. She was disappointed and frustrated. "I thought, 'God, there has to be something better out there.'"

A CALLING UNCOVERED

Growing up in Connecticut, Mundorff, now 46, was always captivated by the stories held in long-buried objects. Her grandmother, who studied under pioneering anthropologist Franz Boas at Columbia University, also inspired her. But it was during a visit to Israel, where Mundorff brushed aside dirt to reveal a mosaic floor of a Byzantine temple, that she got hooked on unearthing history.

As a student at Syracuse University, she spent three summers in Jamaica excavating the slave quarters of an old sugar cane plantation, including bodies buried beneath the buildings. "I was fascinated by the stories skeletons could tell. My first skeleton had gallstones, and I wondered if he even knew," she says.

She worked about five years as an archaeologist in Hawaii and California, jumping from job to job and living out of a duffle bag in hotels and campgrounds. Eventually, her love for the human skeleton drew her into the graduate program in anthropology at California State University in Chico. In 1999 she landed a job as the first and only full-time forensic anthropologist in the Office of the Chief Medical Examiner (OCME) in New York City.

In New York, Mundorff analyzed decades-old bones dug up by construction crews and worked closely with the New York Police Department to help with exhumations. When heavily decomposed, unrecognizable bodies came into the morgue, she pieced together biological profiles to provide investigators with an age range or an indication of the person's height. She considered it her dream job.

SURVIVOR STORY

On the morning of Sept. 11, 2001, Mundorff was pulled from a staff meeting and told that American Airlines Flight 11 had just struck the north tower of the World Trade Center. She and seven others were directed to head downtown to gauge the situation so they could establish a temporary morgue.

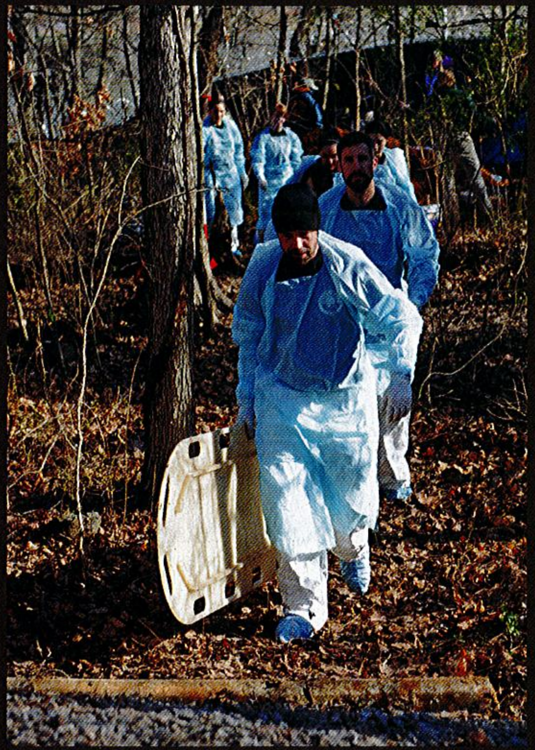
"I questioned whether we should really be going down there. We didn't know what was going on. We weren't first responders. What if there was a bomb or another explosion?" she recalls thinking. "But I pushed my better judgment aside, and I went. It is the only real regret I have in life." The team members climbed inside two cars and raced 50 blocks downtown. Just before they left their offices, the second plane, United Airlines Flight 175, hit the south tower.

Mundorff was standing on West Street, near the Marriott Hotel, surveying the area amid the debris and chaos when she heard a loud noise and turned around to see the south tower crumbling. She started running. The building's collapse created a seismic wave that had a local magnitude of 2.1. Debris surged toward Mundorff, threw her into the air and knocked her unconscious. "I thought I was going to die," says Mundorff. "After it ended, it was just black."

She came to 10 to 15 seconds later on the other side of the street, at the foot of 1 World Financial Center. She remembers hearing sounds. "All the firemen have alarms on their air tanks that go off if they're down for more than 30 seconds. There were hundreds of those alarms going off," she says. Mundorff had been standing within the tower's kill zone — the pressure wave had stripped the stone facade from the building behind her. A fire engine had flipped over; a steel beam had crushed the car she arrived in. She started yelling, "I'm alive! I'm alive!" She dug herself from the rubble and walked toward the river in search of cleaner air.

Two days later — covered in bruises, with cracked ribs, stitches in her leg, a large bump on her forehead and two black eyes — Mundorff returned to work. The remains of the victims who died in the disaster had begun to arrive at the OCME.

Mundorff worked 12 hours a day, seven days a week to



Mundorff and her colleagues break ground at the research site, a wooded bluff on the Tennessee River, in February 2013 (left). Graduate student Jake Smith carries a board used to bring one of the 10 donated bodies to the gravesite (above). By November 2014, the only signs of the graves are white marker flags (right).

FAR RIGHT: HANNAH HOAG

identify the victims. She sat at a triage table at the head of the mortuary assembly line, sifting human bone fragments from building materials and animal remains, and separating unrelated parts. She was exhausted, but unwilling to step back. "I survived, and they didn't," she says. "It was something I had to do. It was my job. I just did it."

LESSONS LEARNED

After three years and 1,598 victim identifications, Mundorff needed a break from the front lines. She also felt that future mass-fatality managers, whether identifying victims of natural disasters, war crimes or acts of terrorism, could learn from the data collected and methods refined in the World Trade Center Victim Identification Project. In August 2004, Mundorff drove to Vancouver, British Columbia, to pursue a doctorate degree at Simon Fraser University.

In her thesis on identifying human remains in the wake of the World Trade Center disaster, Mundorff argued that anthropologists should participate in excavations of disaster sites to note the precise location of remains and exclude non-human remains, which would make the process faster.

Her analysis also found that smaller bones, such as those in the foot or the kneecap, yielded DNA that could be used for identifications at about the same rate as the femur and other larger bones, which, until then, were considered the best options. In disaster situations, time is short and electricity may be unavailable. Removing smaller bones with disposable scalpels instead of bone saws speeds up sampling, reduces contamination and is less destructive.

As Mundorff worked on her thesis, the futility of the search in Bosnia continued to dog her. She would kick around ideas during weekend rock climbing trips with her husband and friends, including Michael Medler, a fire geographer at Western Washington University in Bellingham. Medler uses remote sensing technologies to document vegetation conditions and predict forest fire risk.

"Climbing is a great way to talk about what you can see down below you," says Medler. "I would yammer on, saying, 'You know, these [graves] ought to leave a mark.'"

Medler uses LIDAR, short for light detection and ranging technology. Strapped to the belly of an airplane or helicopter, a LIDAR device fires millions of laser beams down onto the landscape. Some pulses rebound off the forest canopy, while others slip between the leaves like raindrops and ricochet off the ground. Together, they create a 3-D map. The technique has transformed archaeology, giving scientists the ability to peer through dense vegetation and see long-hidden temples, boulevards, dikes and cityscapes — angular human-made structures that pop out of otherwise natural landscapes.

"You know," says fire geographer Michael Medler, who uses remote sensing technology to predict forest fire risk, "these [graves] ought to leave a mark."

The potential for using LIDAR to find hidden graves appealed to Mundorff because it's an aerial instrument. Human rights investigators could use it when it is still too dangerous to send personnel into a post-conflict area.

PLANTING EVIDENCE

By 2007 Medler and Mundorff had resolved to test whether hidden graves could be found remotely, but they needed funding, and Mundorff was still a student. So the idea languished.

After receiving her Ph.D. in 2009, Mundorff took a faculty position at the University of Tennessee in Knoxville. Since the mid-1980s, the university has run one of the few outdoor facilities where scientists bury human bodies to study how they decompose under a variety of conditions. For Mundorff, the move was one step closer to testing whether LIDAR and other remote sensing technologies could be used to find unmarked graves.

Other forensic studies have buried cows or pigs, but Mundorff believed it was important to use human bodies to test the LIDAR idea. Because different species may leave distinct chemical signatures in the soil that could in turn affect how vegetation grew at the site, it only made sense to test the technology on humans.

Mundorff also wanted untouched soil, which the Knoxville site lacked after decades of research burials. She would have to wait more than two years for perimeter fencing to be installed around a new plot of land, recently donated to the university, before she could begin her work.

In the meantime, working with colleagues at Texas State University, Mundorff buried a body on a 5-acre forensic anthropology facility run by the university south of Austin. She hired a graduate student to monitor the site and how plants responded to buried bodies.

Nitrogen is one of the many chemicals bodies release as they decompose. It's also an essential mineral for plant growth. The change in soil chemistry from extra nitrogen could alter the chemical signature of the plants growing over the grave. As a result, thought Mundorff, those plants might reflect red and infrared light differently enough to be picked up by satellites measuring Earth's vegetation. Although the satellite sensors themselves provide only a few points of data per square meter and might not pick up small graves containing a single body on their own, the data they collected might be useful when combined with additional information from LIDAR.

A year and a half after the burial, the grave was covered with grass. The nitrogen levels in the leaves over the graves skyrocketed to five times greater than those in the leaves over the undisturbed soil. The preliminary data supported Mundorff's hypothesis that buried bodies affected the vegetation growing over them.

TENNESSEE JUNGLE

Back in Knoxville, with the fence in place by the closing days of 2012, Mundorff finally got the green light to start her original LIDAR-based research idea. Around Valentine's Day in 2013, Mundorff and a handful of students broke ground at the new site, a wooded bluff on the Tennessee River, opposite downtown Knoxville. Among the students was Katie Corcoran, who recently joined Mundorff's project after working with the Seminole tribe in Florida, using LIDAR and historical aerial photos to find archaeological sites.

The team dug into the earth, dark and streaked with tawny-colored clay, with shovels and pickaxes. They carved out four graves for 10 donated bodies. One grave holds the remains of six people; another contains three; and another fits a single body. The fourth grave, dug to the same dimensions as the six-person grave and refilled, would be the control.

For the next several months, Mundorff and Corcoran's team scrutinized the site in almost every way. A photographer documented the graves as they settled. A botanist surveyed the vegetation and mapped its regrowth. A scientist from the nearby Oak Ridge National Laboratory (ORNL) set up thermal cameras to record the temperature of the graves over 24-hour periods while the bodies decomposed. As the seasons shifted, grasses and shrubs reappeared. Mundorff and Corcoran snipped leaves and tucked them into envelopes so they could analyze their chemical composition.

On a crisp November day in 2014, I joined Mundorff and Corcoran at the burial site. Two fences hemmed in the allotment. Mundorff first unlocked an 8-foot-tall chain-link fence topped with razor wire, then an equally high wooden privacy fence, and swung open the gates. Leaf litter from oak and maple trees covered the ground and crunched beneath our boots. Days of rain had left the clay-rich soil soft.

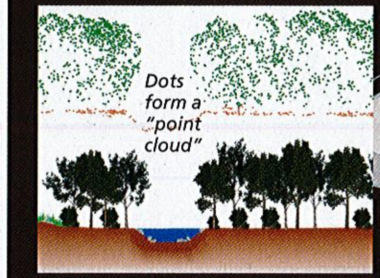
Metal disks stamped with letters and numbers, and nailed to stakes in the ground, identified the graves. Without the markers, they would have been easy to miss.

SEARCH AND RECOVERY

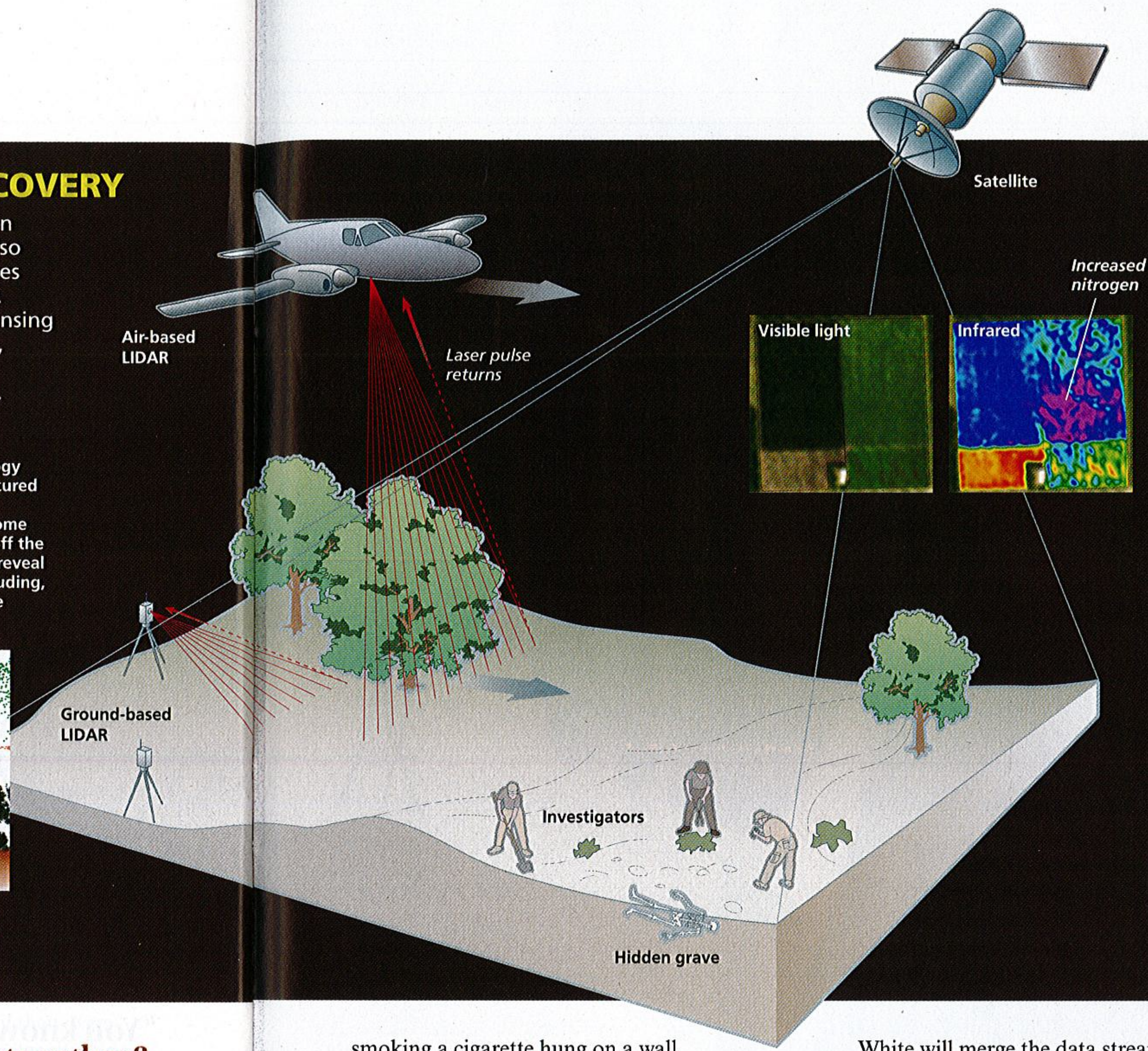
Finding hidden graves is often a hit-and-miss process that also can be dangerous in war zones and other areas of instability. Applying different remote sensing technologies could save time, focus resources and protect those searching for the dead.

LIDAR

Light detection and ranging technology (LIDAR) devices, on the ground or secured to a plane or helicopter, fire millions of laser pulses onto the landscape; some bounce off the forest canopy, some off the ground, creating a 3-D map that can reveal subtle changes in topography — including, potentially, graves that are otherwise invisible to the naked eye.



As the millions of LIDAR laser pulses bounce back from different surfaces, each pulse becomes a dot in a "point cloud" that creates a detailed map.



Satellite Images

Although satellites measuring vegetation provide limited data per square meter compared with LIDAR, their sensors can pick up areas with increased nitrogen uptake, a key chemical signature of a decomposing body. The information, when paired with LIDAR, could signal a hidden grave.

Boots on the Ground

No technology yet exists to replace human investigators in the final step of confirming and documenting hidden graves, but remote sensing technologies could one day perform recon and initial analysis of a potential site.

FROM LEFT: POINT CLOUD BY NATIONAL ECOLOGICAL OBSERVATORY NETWORK/NATIONAL SCIENCE FOUNDATION/ COOPERATIVE SUPPORT AGREEMENT NO. 10298O8; ILLUSTRATION BY JAY SMITH; SATELLITE IMAGES BY NASA/GSFC; PHOTO BY AMY SMOTHERMAN BURGESS/KNOXVILLE NEWS SENTINEL/ZUMA

"If each layer of data is an instrument, how do you get them to all play together? You have to turn it into a symphony," says remote sensing expert Devin White.

REMOTE SENSING SYMPHONY

The next day, the three of us met in Mundorff's office for a sneak peek of the next phase of the research. The space is a cinder-block box with high ceilings and fresh blue paint on the walls, buried beneath the university stadium. Bones and other artifacts sat atop bookshelves and tables, and a poster of Van Gogh's painting of a skeleton smoking a cigarette hung on a wall.

Corcoran loaded onto her laptop LIDAR images collected before the burial. Eight million points populated the screen in a dense 3-D image called a point cloud, showing streets, buildings and hills. With a few clicks, she zoomed in to the site and stripped away vegetation to reveal the contours of the bare earth.

Corcoran switched to a satellite image also taken before the burial. It looked like a photograph, but it was a composite of several spectral bands, each measuring the reflectance of the surface at different wavelengths of light. She highlighted the vegetation by selecting the infrared band. Knoxville's wooded areas and fields glowed red.

These "before" images provide an important baseline that Corcoran and Mundorff can use to compare against the data they're collecting through spring 2016. They've enlisted the help of Devin White, a remote sensing expert at ORNL who has used airborne and satellite imagery to identify ancient footpaths threading through the Sonoran desert between Arizona and Mexico.

White will merge the data streams taken from the ground, air and space, and use it to spot locations of interest. "If each layer is an instrument, how do you get them to all play together and do something more than the sum of their parts?" asks White. "You have to turn it into a symphony."

The week is marked by the arrival of a $200,000 ground-based LIDAR scanner, on loan from the Remote Sensing Center at the Naval Postgraduate School in Monterey, Calif. Although Mundorff's goal is for investigators in the field to use aerial LIDAR, the ground-based unit's data — along with existing aerial and satellite imagery — will help White's computers at ORNL learn what a hidden grave looks like.

Mundorff has faced several challenges during the project and admits there is still a lot of work to do, but she remains hopeful that she can develop techniques that will help find the missing, and potentially bring their killers to justice. She may have stopped doing forensic casework, but she remains devoted to developing tools for those who continue to do the difficult work. "I'm a practitioner at heart," she says. "All my research is about the practice of forensic anthropology." ■

Hannah Hoag is a science journalist and editor based in Toronto.

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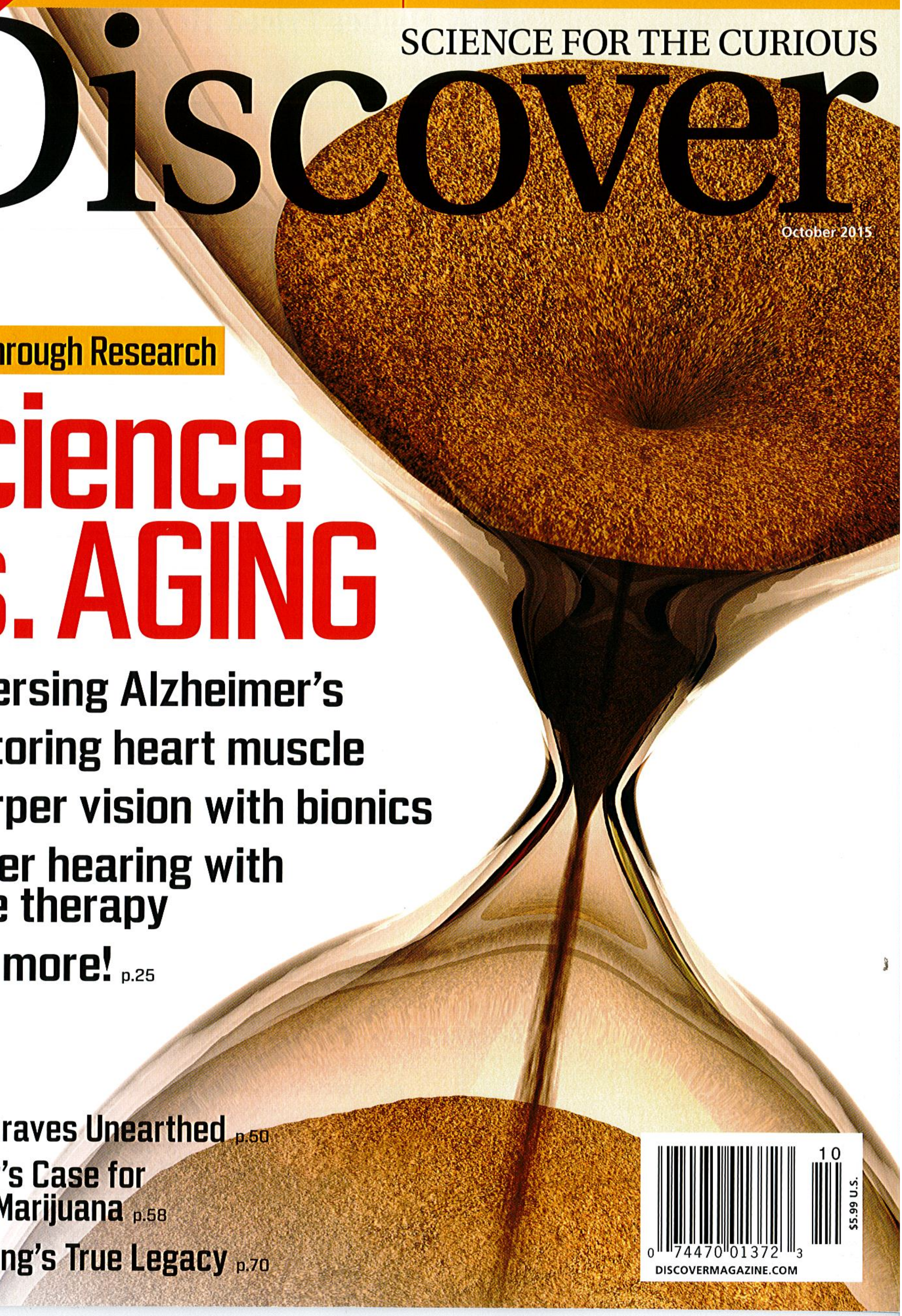

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