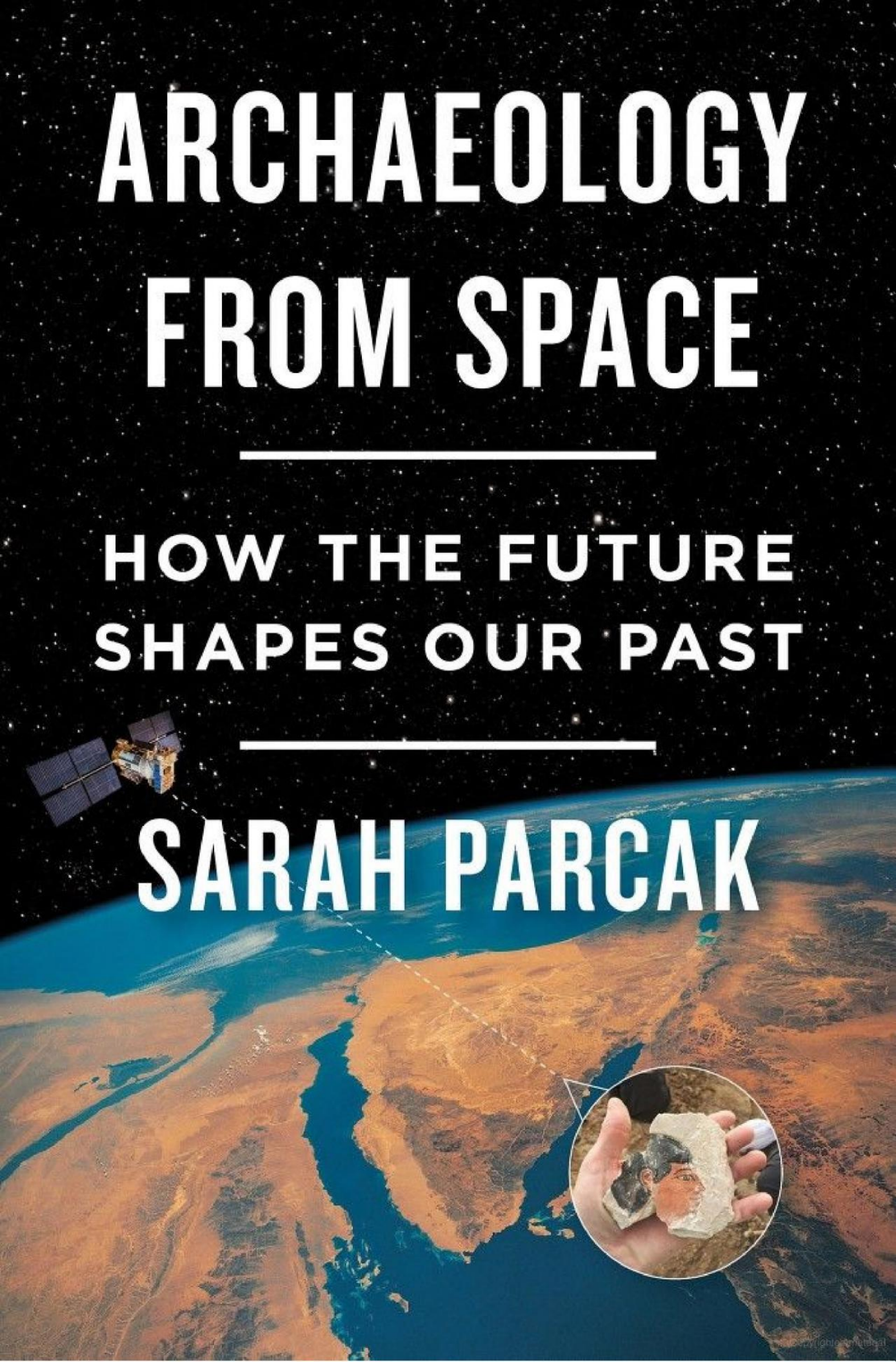
ARCHAEOLOGY FROM SPACE

HOW THE FUTURE SHAPES OUR PAST



SARAH PARCAK

This book is dedicated to Susan Young, our family Pensieve

Note to Readers

The author will donate a portion of the author advance from this book to support the mission of GlobalXplorer, a 501(c)(3) nonprofit organization registered in Alabama. This includes fieldwork and field schools in Egypt, training foreign archaeological and cultural heritage specialists in innovative technologies, and empowering a global citizen archaeology movement. If the ideas shared in this book have moved you, I encourage you to visit www.globalxplorer.org to become a space archaeologist in training.

Introduction

My entire life is in ruins. Quite literally. No, this is not a cry-for-help book, nor a journey of self-discovery. I am an archaeologist. I've spent much of the last 20 years working on excavations in Egypt and the Middle East, exploring ruins in Central and South America, mapping sites across Europe, and even digging for the occasional Viking. You might say I am obsessed with the dirt beneath my feet and all the wonders that might be there; it doesn't necessarily glitter, but it is priceless. That dirt contains nothing less than the clues to who we are, how we got here, and how we might thrive in the future.

Most of us can look back at our lives and identify pivotal moments that influenced our journey to where we are in our career: an unexpected event, maybe, meeting a key individual, an epiphany of some kind. Something. In my case I can identify one influence rooted in fiction and another solidly founded in facts.

Pizza, Videos, and My Path to Becoming an Archaeologist

If you are a child of the 1980s like me, your Friday night routine might have included getting pizza and picking up a VHS cassette from your local movie rental place. Wow, even writing that makes me feel old. After school, my mom would take my brother, Aaron, and me up the street to a creaky old house that had been repurposed to hold thousands of tapes, categorized by theme and age appropriateness.

Much to the chagrin of my mom, we invariably chose one of three movies: *The Princess Bride*, *The NeverEnding Story*, or *Raiders of the Lost Ark*. (Now that I have a child of my own, who wants nothing more than to watch *Minions* on repeat, I appreciate my mom's purgatory. She laughs at me.)

If we chose *Raiders*, I would sit, rapt, memorizing every scene, every bit of dialogue, every gesture. I can't tell you if it was Egypt, the sheer adventure, or just Harrison Ford, but that movie called out to me.

At that age, I didn't know that no one-size-fits-all fedora exists for archaeologists. We specialize in diverse subfields: aside from a particular time period or regional focus, an archaeologist might study pottery, art, bones, ancient architecture, dating techniques, or even recording and illustration.

I'm part of a relatively new specialism called space archaeology. I am not making that term up. It means I analyze different satellite data sets—Google Earth is one you're probably familiar with—to find and map otherwise hidden

archaeological sites and features. It's a pretty cool job, but wasn't an obvious career option when I started taking undergraduate archaeology classes.

Why I do what I do all goes back to my grandfather, Harold Young, who was a professor of forestry at the University of Maine. Every weekend when I was young, while my parents worked late nights at the family restaurant, Aaron and I went to my grandparents' house on a hilly tree-lined street in Orono, Maine. Gram and Grampy had retired, my grandfather from the university and my grandmother from her post there as secretary of the faculty Senate.

Gram ruled the Young household, and the Senate, with an iron fist, so much so that Grampy always gave the same response when we asked if we could go outside to play.

"I'm only a captain," he'd say, smiling. "You'll need to ask the general!" and he'd turn to Gram and give a sharp salute. It ticked her off something awful and sent us into fits of giggles.

Grampy and My Journey into Space

Grampy was in fact a captain, having served as a paratrooper during World War II. Part of the US Army's 101st Airborne Division, known as the Screaming Eagles, he had led a platoon and jumped the day before D-Day. He also led one of only six bayonet charges in the war, receiving a Bronze Star with an oak leaf cluster and a Purple Heart. To plot his landing positions and map where to coordinate his troops, he analyzed aerial photographs, cutting-edge technology at the time.

He took that technology with him when he completed his PhD in forestry at Duke University, developing new techniques to map tree heights using aerial photos. For nearly 30 years, Grampy taught generations of foresters how to use such photographs in their research and became a world-renowned forester.

I was only told about Grampy's careers in snippets over time. He sometimes disappeared, traveling to far-flung places for international conferences, bringing us back carved wooden elephants from Zaire (now the Democratic Republic of the Congo). I later learned he donated his entire forestry library to institutions there. When I was little, I didn't understand what it meant to be a decorated war hero or a brilliant scientist. I just knew him as the kind and gentle grandfather who drove Aaron and me up to the campus to visit the cows in the research barn, where we would get freshly made chocolate milk if we were well behaved, which was rare. To this day I still think chocolate milk comes from chocolate cows.

Most of all, I remember how he'd let us look through his stereoscope,[1] like a set of desk-top binoculars, under which you put two slightly overlapping aerial photographs. The effect is wonderful—the photos jump out in 3-D. It's not something you forget, if you're young and impressionable, and it mapped out the first steps on my path.

Like so many in the Greatest Generation, Grampy never spoke about his war service. I did try to interview him for a high school project, but those days, thank God, were behind him. The forest was safe, and full of trees to map and identify, and that's where he took us, without fail. Grampy ran three miles every day, and still had the strength to walk around the neighborhood the day

before he died from cancer.

Three years after we lost him, as I gradually learned more about his research, I increasingly regretted never discussing it with him. By then, his research papers were available online, and my curiosity about his work had deepened to the extent that I took an introductory class on remote sensing in my senior year in college. Grampy had never gotten into satellite imagery—it came into use in forestry about 15 years after he retired—but I wondered just how different it could be from his aerial photography. Besides, most archaeologists had probably already included the technology in their research, especially in Egypt. Right? Everything had likely been mapped. Oh, naivety!

I started to get a clue when I tried to find papers for my final project, using satellites to detect water sources near archaeological sites in Sinai, Egypt. You know you've hit a dead end when the handful of sources cite each other. That one class led to a master of philosophy thesis, which led to a PhD, and now nearly two decades of research. I have my grandfather to thank for my career.

The Hat, My Past, and the Future

As an archaeologist, I felt this connection to my grandfather made a lot of sense. Your quirks, the way you look, your likes and dislikes, are only the surface of the archaeological site of You. Our ancestors are the underlying layers of earth, enhancing our lives in ways we may not even comprehend. So much is buried deep within your DNA, and in the DNA of the landscapes where humans live today and lived thousands of years ago. We just need some perspective to pull back and see the clues and connections between us and within us.

With that perspective firmly supporting us, our dreams can take us anywhere. When I watched *Raiders of the Lost Ark* as a child, if you had told me that I would spend my career becoming a space archaeologist, I would not have believed you. And there's no way that I would have believed I'd ever meet the man himself, Harrison "Indiana Jones" Ford, complete with that hat.

It happened in 2016, when I gave a TED[2] talk in Vancouver in which I described my work as a space archaeologist and my dreams for its potential. By this time I was an archaeologist, just like Indy. I heard a rumor that Harrison Ford might attend the talk, but I was told not to get my hopes up. Well, my luck held, and he came to the conference. My dear friend Tom Rielly, founder of the TED Fellows program, helped organize a luncheon for Harrison to which I was invited. I don't think I slept a wink the night before.

As he approached, my heart raced. He looks exactly like he does on camera—the same craggy, rapscallion handsomeness. While we shook hands, he said all sorts of very nice things about my talk the day before. There was one thing I just had to get out in the open.

"Indiana Jones helped inspire me to go into archaeology," I told him, "and inspired so many in my field. From all of us, thank you."

"You do realize that I was just a character, right? You know more lines from that movie than I do."

"Of course it was a movie, but it was your spirit that made Indy come to life. That was an inspiration from the start. And that's why I'm thanking you, from the bottom of my heart."

Maybe he's just a very good actor, but I genuinely do not think he understood the impact he'd had on recent generations of our field until that moment.

Lunch with him and my husband was amazing. Harrison humored my overexcited archaeo-babble; he's more into wildlife conservation activism than heritage, but he is a very gracious and kind human being, with one hell of a rakish grin. I will always be grateful for his bemused listening.

After lunch, we went outside for photographs, and I produced a brown fedora. Harrison looked at me and shook his head.

"I can't believe you brought the hat."

"I couldn't resist," I said. He laughed.

"Since you're the real deal, you get away with it."

Yes, there is a photo of us fighting over that thing, and I will treasure it forever.

The Scope of Space Archaeology

The human story—the story of us—is evolving at breakneck speed thanks to new technologies. Armed with new data sets, we can spin fresh tales that bring us closer to getting more right than wrong about our ancestors and ourselves.

What we can find with new technologies such as satellite imagery is simply astounding. It is helping us rewrite history. We've gone from mapping a few dozen ancient sites in one summer-long archaeological season to mapping hundreds, if not thousands, of sites in weeks. With advances in computing and artificial intelligence, we are on the verge of achieving those same results in a few hours.

In case you want to be an archaeologist and are worried that we space archaeologists will find everything first, fear not. Knowing the location of an ancient site is only the first step. We still have to survey sites on the ground, a process known as ground-truthing, and then undertake years of excavation to get a better understanding of what is there. And wow, do we have a lot of work to do.

To give you a sense of just how much, and how quickly this field is advancing, I saved writing this introduction until last, to make sure to include any hot-off-the-press discoveries made with satellite technologies. With the chapters done and edited, I thought I could get away with a bit of downtime between big announcements. Dream on, Parcak.

In a recent *Nature* publication, a team led by archaeologist Jonas Gregorio de Souza announced 81 previously unknown pre-Columbian sites in the Amazon basin area of Brazil, using satellite imagery and ground surveys. Based on their findings, they estimated 1,300 other sites dating to between 1250 and 1500 AD in just 7 percent of the Amazon basin, with potentially more than 18,000 others in total. More than a million people may have lived in areas that today seem largely inhospitable.

Their findings included ceremonial centers, large platform mounds, ringed villages, and fortified settlements in north-central Brazil's upper Tapajós Basin, where few archaeologists had ventured.[3] To me, what is extraordinary about this discovery is just how much archaeologists and others had taken for granted about what might, or might not, be there in the rainforest. Satellite data

allowed the archaeological team to search large areas in a matter of months, when the job would have taken decades on the ground. All this, from a subfield that barely existed 20 years ago. Although the world is learning more, there's still a way to go in popular understanding. In a recent travel insurance application for my work abroad, I was quoted an insanely high price for one year of coverage, over $50,000. When I inquired why, the team admitted they thought I traveled into space to look down from the actual satellites for ruins. I'm still laughing.

As I write this, I am downloading brand-new satellite imagery of Giza, in Egypt, the site of the last standing wonder of the ancient world. Who knows if I'll find anything previously undiscovered there. The main thing I have learned is to expect the unexpected. New sites and features appear where you hadn't previously thought to look, or, in cases like Giza, have the potential to overturn long-held assumptions about major sites and time periods. In the following chapters, you'll read about projects that did just that.

Mapping sites from space is fun, but getting to explore them is what takes me back in time, often thousands of years, to eras when people believed in different gods, spoke languages now extinct, and lived in places assumed never to have been inhabited—but they were all *Homo sapiens sapiens*. Just like us.

As such, archaeology has the potential to inspire in us great wonder, bringing us together. Today, given the conflicts and unrest around the world, this is very much needed. Some people don't get the chance to experience that sense of awe in person at ancient sites, but I hope the stories shared here will give a sense not only of this, but of how much we assume about past peoples, and how wrong we have sometimes been, given our access to such fragmented information.

There aren't any papers published yet on whether remote sensing can complete the puzzle of what it means to be human and how to avoid the pitfalls of great civilizations that came before us. All I can say is that there is extraordinary wisdom to be learned from previous cultures. It's shaped me profoundly and allows me to place current events in the long arc of perspective. For more than 300,000 years, our ancestors have migrated across Planet Earth, surviving and, in some cases, thriving—being creative, bold, innovative, and, of course, destructive.

This story of space archaeology, its contributions to research, and the tales it helps us tell, only introduces the possibilities of the science. The scale of these new stories, however, should amaze and inspire us. In our history on Earth, humans have habitually pushed deeper into the unknown; as we now begin to focus on exploring Mars, and farther afield, we can imagine 100,000 years from today, when there will be literal space archaeologists traveling from planet to planet, exploring the remnants of our early settlement efforts in other galaxies.

The origins of their field will be many light-years away, but the questions will remain close to those we ask today, about people who came before us. The answers matter far less than those questions. Perhaps it's a start to understanding what makes us human: our ability to ask how, where, when, why, and who, and creating the tools we need to bring the answers to life, on Earth, looking down from outer space.

1

Time Capsule

Nothing prepared me for the moment I saw ancient ruins for the first time. I was traveling to Cairo one afternoon in 1999. Whether by luck or divine intervention, I sat on the left side of the plane, peering out the window as the airplane flew low over the Pyramids of Giza. I gasped in disbelief. Everything I had ever dreamed of lay before me in the form of 4,500-year-old weathered golden limestone, bathed in sunlight, inviting me down—and in—for the rest of my life. Even today, after many visits to Giza, visiting the pyramids shocks my system. As an Egyptologist, I understand the current line on how and when and why the ancient Egyptians built those tombs for the great kings of the Fourth Dynasty, with an estimated 20,000 men. But the intimate knowledge does not dull my amazement.

I had made that trip to Egypt to take part in my first excavation. For the two weeks before the dig started, I traveled around Egypt by myself. (I want to turn to 20-year-old me and ask: "What exactly were you thinking?") It was a grand adventure. Among many wonderful occurrences, I met a group of older Taiwanese tourists on the island of Philae in Aswan, and they invited me on their luxury four-day cruise down the Nile. The tour director charged me only $200 for the entire trip; I was told I would be an "archaeological ambassador." My heaviest lift involved teaching the Macarena to several grandmothers in an art deco–classical mashup themed discotheque.

Weirdly magical though archaeology can be, my work often takes me far from those glamorous heights. I dig for ancient answers in places that do not look like much: a casual bystander might not assume that a modern soccer field next to a school could hold discoveries worthy of global headlines. But even if the site is not as gloriously intact as the Giza pyramids, it is my job to re-create with words or models what time has virtually destroyed.

There's no typical ancient site, even within the same country, and preservation varies from place to place. Only 20 kilometers south of Giza, you see towering, misshapen mud-brick hills, the melting interiors of pyramids built much later that have succumbed more rapidly to the depredations of people

and time. Likewise, archaeological sites can range in size from great settlements to tiny campsites in the desert.

Let's just fine-tune the definition of a site, for a moment. Walking through the woods of Alabama, especially near lakes or streams, you might find clusters of arrowheads or other stone tools. Each one of those clusters is considered a site.[1] The same is true if you walk in the deserts of the American Southwest. You could encounter a larger unmapped site, such as remains of a building or even a village, but most likely it'll be a tiny scatter of ceramics, stone implements, or the remains of a small campsite.

Sites Are Filmstrips, Not Photographs

Among the suggestions of what once existed, the promise of our own future demise is readily evident. In English, we say "ruin." The word connotes destruction and suggests something negative, rather than normal or inevitable. In Arabic, on the other hand, my favorite word is *athar*. It can be roughly understood as "archaeology." Linguists would tell you it's more finely translated as "remnant," which suggests the remains of an ancient culture that hint at a hidden completeness. When you say, "Ana doctora athar farony" ("I am a doctor of the archaeology of ancient Egypt"), people understand your profession as Egyptologist. Archaeologists are thus professional "remnant-ologists," dealing in fragments of pottery, bits of amulets, and random pieces of hieroglyphic text, all waiting to be woven together.

The case of Palmyra, the great multicultural Syrian city at the edge of the ancient East-West divide, has sparked a modern confrontation revolving around different interpretations of the word "ruin." In 2015, the Islamic State of Iraq and the Levant, or ISIL, blew up the Temple of Bel and a graceful series of columns at Palmyra. Turning a venue for concerts and tourist picnics into a place of nightmares, ISIL conducted executions in the well-preserved Roman amphitheater and displayed their murdered victims among the ruins, including the great archaeologist of Palmyra, Dr. Khaled Al-Asaad.[2]

Debates have raged in the archaeological community about rebuilding the temple, using archival photographs as guides. Some people think it would be beautiful, and appropriate, to see that glorious old site rise again in splendor. But here's the complication: Palmyra traded cultures many times until reaching its height under the empress Zenobia, whose reign ended in 272 AD. The Roman emperor Aurelian allowed his soldiers to sack the city in 273 AD. Then in 1400, the Timurids razed the city again, reducing it to a small town.[3]

What we see at the site of Palmyra today is a complex series of layers of destruction, the remnants of global power struggles and shifting political alliances—including ISIL's occupation. Some feel that to reconstruct the Temple of Bel is to erase ISIL's atrocity instead of recognizing it and honoring the shattered moment in perpetuity so that we do not forget.

Sites are not static. They are akin to a filmstrip through time, in which building and destruction alternate, sometimes concurrently. As we do our best to capture these partially obscured images, places exist in our imaginations, ideal or ruined, evoked when we first step into the liminal zone of a site. We face past and present, all at once.

Projecting a Single Frame

Capturing a snapshot of exact moments, or even periods of time, is difficult. One reason is that few well-preserved examples of ancient cities exist in the world. The most famous is Pompeii, frozen by a volcanic eruption. Anyone who studies the past must smile, seeing tourists gawk at reliefs of phalli near Pompeii's brothels.[4] It's the sense that Roman Pompeiians and modern oglers share that same reaction, 2,000 years apart.

But even here, there is still something missing. Or rather, some*one*—a lot of someones.

Ancient sites are ghost towns. If anyone from antiquity happens to be there ... run. Without a sense of its people, sites become places of monuments, not of activity, however difficult it is to reconstruct the motivations and aspirations of communities who lived thousands of years ago. Context of the material culture they left becomes everything, so we gain insights into use, function, and purpose, to reach the people behind the objects. After carefully collecting the evidence, we study how each piece relates to the others, and squeeze every last drop of data and insight we can from them.

Some people believe sites contain echoes of their former inhabitants. Whatever your beliefs, consider a place like Deir el Medina, the Egyptian New Kingdom village where workers who built the tombs in the Valley of the Kings lived.[5] Today, you see the whole community outlined in mud-mortared limestone walls that survive to a meter or taller. The site tempts you to imagine what happened 3,500 years ago, in the two-story homes that rose from those footprints. Cut off from views of the nearby fertile Nile floodplain, you feel as though you're moving through a secret and sacred place, home to the great artisans whose work fuels feverish archaeological dreams today.

We See Dead People

Archaeologists can find signs of ancient lives if we look hard enough in the thumbprints on pottery, the chisel marks left on stone, and everywhere in the beauty of things designed for people long ago.

But cemeteries, naturally, represent the best bet for finding the actual remains of people. They're typically placed away from living spaces in defined areas for the dead, in some cases near holy sites; think of burial grounds near churches.

Getting to know an actual human being from their bones is not easy: it's the specialist job of physical anthropologists, who also go by the science-fictional-sounding term bioarchaeologists. Skeletons contain a wealth of data about us. If enough well-preserved bones turn up and you know what to look for, you can usually ascertain an individual's sex, height, nutritional status, and approximate age, and sometimes the diseases from which the deceased suffered —and which may have been the cause of death. Even teeth tell tales. Avid followers of the paleo diet would hardly be so keen on the paleo dental plan, which included treating cavities with flint tools.[6]

Also, through the overall health of the bones, the context in which they're found, and any associated grave goods, archaeologists can suggest the social

status of the individuals. Repetitive motions over a lifetime leave their mark in ways that inform anthropologists and sometimes reveal occupations. At Tell Tebilla,[7] a site two hours' drive northeast of Cairo, an excavation team led by my husband, Gregory Mumford, came across a case of art brought to life by archaeological evidence.

Map showing the location of Tell Tebilla [MAP COURTESY CHASE CHILDS]

We excavated a burial of a woman with very strong muscle attachments on her left shoulder. This might have been quite a puzzle, but an artifact in the Metropolitan Museum of Art suggested a cause.[8] The carved wooden image depicted a young woman in a colorful beaded dress carrying an offering atop her head—supporting it with her left hand. Our lady at Tell Tebilla had apparently spent her life carrying heavy loads in a similar way, just as modern Egyptian women still do, deepening the muscle-attachment groove of her larger-than-normal left bicep.

Occasionally we find that ancient people suffered from problems that are usually thought to be modern. In an analysis of 22 mummies at the Cairo Museum, bioarchaeologists found evidence for atherosclerosis, or hardening of the arteries, in more than half the individuals. Most probably, it seems, these people ate too much beef.[9]

By assembling data about the dead from sites of the same time period and looking for patterns, we gain insights into the population that allow us to make inferences about why things happened for that entire culture. Perhaps disease overtook society, affecting specific groups. Or a famine wiped out everyone. Too many skeletons from healthy, strong young men could even suggest war.

Ages at death can, ironically, indicate whether the population is healthy. Physical anthropologists will tell you that they expect to see specific ages

represented across the spectrum in a cemetery, and when adult ages skew too young, something significant happened to cause the high number of otherwise healthy young adults' deaths at that time.

Methods like DNA research open new possibilities into understanding the past, such as piecing together family relationships from the interwoven tendrils of our ancestors. A recent study on the mummies of two supposed brothers tells a fascinating tale worthy of any daily talk show. The mummies of Khnum-Nakht and Nakht-Ankh, dating to the Middle Kingdom, around 1800 BC, have sarcophagi with lifelike carved faces. They reside at the Manchester Museum in England.[10]

Using DNA sequencing, researchers discovered that the mummies belonged to mitochondrial haplotype M1a1, showing they had the same mother. But differences in the Y chromosome meant different fathers.[11] I have *so* many questions. Did the father of the older brother die, leaving the woman to remarry? What struggles did she face as a widowed mother? We'll never know, but the data helps us to imagine the possibilities and allows us to be more empathetic.

Ways to Get Closer to the Past

Reimagining the past requires a leap of faith accompanied by a healthy dose of science. We cannot travel back in time to see people smelting copper or mummifying the dead, but we can re-create past technologies using experimental archaeology.[12] This allows us to rebuild features like ovens or kilns based on archaeological findings and their associated fuel sources, and reproduce everyday tools, pottery, and swords.[13] Archaeologists have made innumerable breakthroughs discovering how and why past people made things, although some techniques remain difficult to re-create, such as the complex inlays in ancient jewelry.

More successfully, Kumar Akhilesh and Shanti Pappu looked at the waste products from the production of lithic stone tools at the site of Attirampakkam in northern India. Dating to the Acheulean era, 1.76 million to 130,000 years ago, the site contained evidence of the production of thousands of lithic tools. The team used experimental knapping to learn more about ancient techniques, and the study helped them to understand decisions past people made about stone sourcing and manufacturing processes.[14]

My Egyptologist colleagues have even conducted real-life mummifications of animals that had died naturally and, for one television show, of a man who had volunteered for the treatment prior to passing away.[15] Maybe when they finished filming that segment, they said it was a wrap!

Another field of study, ethnoarchaeology,[16] focuses on how cultures today may connect to past groups in the same area. Clear differences exist between the pottery workshops of the modern Egyptian Delta and those from ancient sites, yet when I visit, I find potters hunched over their wheels in the same way that's depicted in ancient Egyptian models. Potters today add straw, or chaff, to their clay to strengthen it for firing, just as the ancient Egyptians did; if you peer through a magnifying glass at the edges of ancient pottery fragments, you can see clear chaff imprints.[17]

Cognitive archaeology[18] takes the experiment even further, attempting to deconstruct the actions and thoughts of past people, and how they experienced their worlds. We can gain these insights not only through the study of cultures' material products and architecture, but from their languages and the landscapes that inspired them.

Sometimes, though, we get a fortuitous download of ancient thoughts in the form of letters, and we can imagine the person scribbling away, carefully choosing words. One of my favorite letters dates to 1,800–1,900 years ago, from the Egyptian site of Oxyrhynchus. In the letter, a young boy, Theon, vents his anger to his father that he had left for Alexandria without Theon. He says he will not speak to Dad or even eat, unless he reconsiders taking him to the big city.[19] You can see him sulking and refusing dinner—then sneaking to the kitchen later on. Doesn't any teenager today throw fits for being kept out of grown-up business?

Panning Out

But to scale up from familial relationships and out to site relationships with the surrounding landscape, we need more perspective. Spatial imagery of all kinds can give us this data. While we cannot see everything as it once appeared, at least we can get enough clues about the ancient locations of rivers, canals, lakes, and the likely size of sites to make a decent reconstruction. Satellites and aerial data can see only so much, and they still require testing on the ground: we can guess from space, but we cannot know what is beneath the pixels.

Unexpected people find things in unexpected places that show us how little we know. In 2004, Abdullah Al-Saeed, the leader of an amateur archaeological group, found enigmatic features in western Arabia's lava fields.[20] He did not realize the extent and scale of these "gates"—a new archaeological site type—until four years later when he turned to high-resolution satellite imagery available on Google Earth and Bing.

Al-Saeed sent the images to David Kennedy of the University of Western Australia, who is well known for his aerial archaeological surveys of Jordan. Kennedy then located 400 of these features up to 1,600 feet long, some of which could be more than 7,000 years old. This concentration of stone structures may indicate large-scale landscape design during a wetter period, perhaps a water diversion or flood management system. Ground surveys are planned to explore them further, but the story shows how new chapters can be opened for areas considered inhospitable and uninhabitable today, all because a single structure intrigued interested private citizens.

This discovery tells a tale of widespread human–landscape interaction over time; but reconstructing a single important episode in human history can only be done with a caveat. "Once upon a time" are the hidden words in every archaeological report. Most of us have a hard time reconstructing what happened last week in our own lives, but archaeologists must try to reconstruct entire ancient life spans. We are continuously editing our anecdote mechanisms, adapting our sagas for the latest publications and conference presentations—it's something of a balancing act between science and fiction.

Once upon a Time ...

Here's a story, then, inspired by a surprise discovery from space at Tell Tebilla. It captures the beginning of the end of Pharaonic Egypt more than 2,000 years ago.

The year was 343 BC. An anxious Persian king named Artaxerxes III sailed southwest down a Nile tributary. His history lessons might have taught him that this land was once a swamp, where dense marshes filled with crocodiles prevented foreigners from entering the country. Now, a large river entrance stood clear for him, between islands of reeds, leading straight to a city known as "the beautiful mouth," or Ro-nefer, in the local language.

Artaxerxes commanded a 40-meter-long galley with 200 men, flanked by an armada bearing his army, hungry for battle and the possibility of plunder. This town would not disappoint. Spies had told him of its treasures—gold and incense from Nubia, lapis lazuli from Afghanistan, and luxury wines from the Greek islands: after all, it was the northernmost trade port in Egypt.[21]

Three-story houses of affluent merchants, densely packed, appeared across the reed beds as the ship rounded a bend in the river. And at the city's heart, the huge fortified wall of a temple loomed. Artaxerxes had studied his strategy well enough to know that tearing it out—throwing down the walls and destroying its idols—would break the citizens. His men rowed quietly through the early mist, and the king perhaps allowed himself a small smile. Ro-nefer would not last the morning.

Today, Tell Tebilla appears as a brown mound, rising abruptly from lush, neon-green rice paddies. When you drive onto the site, the only hint of its ancient date is a small cluster of thick-cut limestone sarcophagi near the edge of a defunct water-treatment plant of pink brick. The village of Et-Till sits around the site now, home to a thousand rural souls, a far cry from the ancient cosmopolitan city beneath their feet. Around 200 years ago, the mound measured a kilometer by a kilometer in size. Now it is one-tenth that. Over time, farmers have hauled away most of the phosphorus-rich soil, called *sebakh*, to use as fertilizer.

Archaeological work began at Tebilla in the early 1900s, when French archaeologists found statues of seated scribes dating to ca. 600 BC.[22] Egypt's then Supreme Council of Antiquities brought the site to the attention of my husband, Greg, in the late 1990s, when he mentioned an interest in starting an independent excavation mission.[23] No published work on it had appeared in nearly a hundred years.

Excavating the Beautiful Mouth

Our initial survey confirmed the location of a temple, based on the architectural fragments around the water-treatment plant. Built by the United States Agency for International Development to combat unsanitary drinking water, such plants can be found overlaying sites across Egypt, and their presence often made mounds into targets for further development, including the construction of schools. The unfortunate siting caused heavy losses to the study of urban archaeology.

Construction of the water-treatment plant here had destroyed the temple building's foundations, and we could only guess at what it looked like long ago. Our goal for investigating the site included mapping it and finding out about the ancient city of Ro-nefer and the people who had lived there.

Named for the regional capital, Mendes, some 40 kilometers to the southwest, the Mendesian branch of the Nile flowed by the site in antiquity, but no clues appeared on the surface to tell us anything else. We began our work with coring at and around the site, to get a sense of its past size and the location of the ancient river course. Our geoarchaeologist, or geology specialist, a gray-haired, bearded, energetic imp named Larry Pavlish, carried out the coring and a magnetometer survey to reveal the hidden mud-brick foundations of the buildings underfoot.

Coring is like taking on a layer cake with an apple corer—a narrow round auger is rotated down, allowing archaeologists to see layers of earth without having to excavate. It's simple, but very valuable, keyhole archaeology. Magnetometry is slightly higher tech. Passing a portable magnetometer over a site's surface reads differences in the magnetic properties of buried walls or other features, building up a glimpse of their shape below ground. Both techniques help to target where to dig.

Once Larry generated a detailed map of the highest part of the mound—the "Tell" in Arabic—we selected key areas for excavation.

Our team formed a motley, United Nations–like crew, with members from Canada, the United States, the United Kingdom, and Egypt. We stayed in nearby Mansoura, a beautiful city famous for its riverside walkways and its handsome women. The Marshal Hotel was our home away from home and the source of the mango buffalo-milk ice cream that we craved after a day beneath the harsh sun. We confounded its guests by tramping through the lobby in our filthy dig clothing and, on one occasion, carrying a purpose-built wooden toilet for our on-site outhouse, complete with an antique toilet-paper holder.

To beat the heat of the day, we'd rise at 4:30 a.m. for quiet cups of instant coffee and cookies in the lobby, cursing ourselves for having decided to work in archaeology. It's an ungodly hour to be conscious, yet it is de rigueur for those of us who work in the Middle East in summer months. For the commute, two 1960s Peugeots—one with an exposed propane tank in the back—was how we rolled in the Egyptian Delta. On-site by 6 a.m., we'd drive to the top of the Tell to catch the first pink light snaking through the morning fog. Our local work crew would meet us and shake hands, decidedly more awake than we were.

That summer, we worked hard dispelling the long-held myth that Delta sites, being moister than those in Upper Egypt, have poorer preservation of organic materials. Every Egyptologist knows desert sites—so dry that nothing decomposes—have it all in comparison. Well, that's not entirely true.

In one excavation area, we dug down more than 7 meters, revealing a 2,600-year-old three-story house that had been reused by later Egyptians as a mausoleum. A precarious climb down two sets of ladders, each 4 meters tall, took us to the bottom; the record of 500 years of occupation and abandonment unrolled on our graph paper as we planned the earthen section.

And the finds! The site yielded Greek pottery from the Mediterranean, carnelian from Egypt's Eastern Desert, lapis lazuli from Afghanistan, and gold

from Nubia—all evidence of a thriving international port. Based on the coring data and the landscape reconstructions, we knew that water surrounded Tebilla for nine months of the year in antiquity; this, with its location along the edge of Lake Manzala, made it a prime spot for importing and exporting luxury goods from home and abroad.

It would be unusual for a port town in Egypt's Late Period not to have a wealthy temple with a powerful priestly class. It's an era we hardly hear about on TV or in major archaeological announcements; but if you're looking for ancient examples of cosmopolitan and diverse places that mirror modern times, the Late Period is a good time to start. The arts and technology flourished, with innovations in the use of iron, cavalry, and triremes, and a new form of Egyptian writing, Demotic. Numerous new temples appeared throughout Egypt, including the temple at Tebilla.

Some Historical Context

A brief spin through history helps put this in perspective: after international expansion during the New Kingdom and the rise of the priesthood during the Third Intermediate Period (1069–525 BC), the Late Period began with a Libyan takeover from the west in 945 BC. Then the Nubians of Dynasty 25 came from the south, between 760 and 656 BC.[24] Founded around 664 BC, Dynasty 26 represented the last gasp of Pharaonic Egypt as we know it.

Psamtik, the first ruler of Dynasty 26, threw off Assyrian occupation using Greek mercenaries, stabilized the country, and moved the capital to Sais in the western Delta, only 75 kilometers from Tell Tebilla.[25]

For a time, Egypt had stability and foreign alliances across the Mediterranean and eastern Africa.[26] But for all the international diplomacy, the Late Period eventually brought multiple players to the poker table and left Egypt with a diminishing hand and nothing in the pot.

In 525 BC, the Persians took the country. Egypt kicked them out in 404 BC, and spent the next 60 years resisting a Persian comeback from power bases in the Delta.[27]

This served Tebilla well. In 398 BC, Egypt's capital moved from Sais to Mendes, the large city to Tebilla's southwest. Tebilla likely expanded its influence and wealth over the next 19 years during Mendes's tenure as capital, and merchants flocked to the city to trade in the goods flowing across the fluctuating empires. The temple's riches surely must have grown by the time the capital shifted once again to the central Delta. Four more dynasties had come and gone, but who at Tebilla cared, when the port stood stacked high with goods? They would not have known what hit them that misty morning, some 2,400 years ago.

Tebilla's Downfall

Herodotus called Artaxerxes III "a great warrior," and he was certainly tenacious. He attacked Egypt again and again, first as head of the army and heir to the throne in 359 BC, and then as king of Persia, having knocked off 80 of his nearest and dearest at home to maintain control.[28]

In 343 BC, having had enough of Egypt's refusal to be defeated, Artaxerxes brought more than 300,000 men. He engaged Nectanebo II, the last Indigenous ruler, and his navy along the branches of the Nile in the Delta.[29] Nectanebo ran away to Memphis, crook and flail between his legs, leaving garrison towns and ports like Tebilla to fend for themselves.

The battle did not end well for Tebilla's inhabitants. One humid July day in 2003, our team made a discovery that encapsulated Artaxerxes's triumph—a discovery made possible by 40-year-old photographs taken from space.

These came from a covert program in the United States spurred by the Cold War. The CORONA program gathered thousands of images of countries in the 1960s and early 1970s, freezing them in time prior to large-scale landscape changes caused by the construction of dams, urbanization, population increases, and climate change. Luckily, cameras pointed toward North Africa and the Middle East recorded sites that are now damaged or no longer there—and had so much to say about the archaeology of Egypt's demise.

When I examined the 1972 CORONA imagery for Tebilla, corners of a large rectilinear feature appeared in the north-central and south-central parts of the site. Could this be the temple enclosure wall we had hoped to find?[30]

Magnetometry and associated excavations had given us an idea of the town's layout,[31] but locating the edge of the wall on the ground would not be an easy task. Typically, remote-sensing specialists take aerial photographs and georeference them—which means we connect the photographs to current satellite imagery and give each pixel an *x* and *y* coordinate on the map. You need a minimum of six recognizable and unchanged points in the aerial photograph for this process to work. Older, smaller, nondigital images can be stretched to match up with modern imagery, to achieve the same pins-in-the-map effect. This process—and I am not making this up—is called "rubber sheeting."

CORONA image of temple enclosure wall at Tell Tebilla [IMAGE COURTESY OF THE US GEOLOGICAL SURVEY]

But georeferencing older images is an imprecise activity where so much of

the modern landscape has changed. Although I tried with the 1972 CORONA image, there just was not enough of a match, likely due to distortion caused by the rubber sheeting. Finding the wall on the ground with that image alone was impossible.

The initial magnetometry work covered several 20-by-20-meter grids, highlighting buried mud-brick architecture. But this data did not show a large enclosure, either. We knew the temple walls would be several meters thick and more than 100 meters long. Locating it in the remaining month of the dig season suddenly seemed like a major challenge.

Greg had a brilliant idea: scraping away 10 centimeters of the site's surface to reach the top of the mud-brick level buried below the silt. But scraping down *the entire site* would have taken weeks. Instead, where the imagery gave the wall's broad location on the mound, he divided the ground into a grid of 10-by-10-meter squares. We then scraped a small window between each. It was like probing between paving slabs to see what was underneath, rather than taking up the whole patio.

Photograph of excavated enclosure wall at Tell Tebilla [PHOTO BY THE AUTHOR]

Outlines of the buried structures emerged at set intervals. A temple enclosure wall should appear as dense mud brick, with no structural breaks. When we hit an area that fit this description, we just kept scraping until we found two wall edges, some 8 meters apart. Aha! Massive mud-brick wall *here*, and it matched the wall thickness observed in the CORONA satellite imagery. Bingo.

What the Walls Saw

We continued almost 100 meters to the south, until we hit a 90-degree turn to the west. All sorts of interesting things happen in the corners of ancient buildings: foundation deposits, datable material—and we didn't have anywhere to go but down. So, down we went.

Which crew member gets assigned to what excavation unit is always a roll of the dice. This one became my responsibility. I gridded out a 2-by-2-meter unit

in the southeast corner and started digging through the dense silt. Surprisingly, the silt did not change in consistency or color as I went down 10 centimeters, 20 centimeters, 30 centimeters. Neither did it contain objects or pottery.

Just as I was giving up on the unit as a bad bet, I struck a strange, crumbling red brick. And another. And another. Instead of forming part of a wall, the bricks sloped downward at a sharp angle. As more of the feature emerged, it seemed as if someone had dumped several dozen mud bricks in the corner and set them on fire.

After planning, mapping, and photographing it, I started to remove the brick layer. But a glint of gold stopped me in my tracks—gold is as rare as hen's teeth in a settlement context. Then a bronze piece about 5 centimeters long came up. As my workmen sieved each bucket of earth, more gold foil appeared, stuck to what looked and felt like charcoal. The trickle of objects turned into a fire-hose stream: bronze, lapis lazuli, beads, carnelian, and almost a quarter of a sandwich bag of gold foil from the sieve. It had our team puzzling over the burning, and this confused scatter of precious objects, going down more than 80 centimeters.

Across the Tell in our tented recording area, while cleaning the objects so that she could draw them, our dig artist-registrar Shakira Christodoulou teased out their meaning. From the encrusted dirt, beautifully cast bronze appeared—crowns of various kinds, plaited beards, ram's horns—all with tenons, projecting pieces for attachment to wooden statuettes.

But not just any statuettes: the gold foil and bronze were all that remained of divine figures. Tebilla's gods had gone up in flames. Gold was the flesh of the gods, and the bronze symbols of their power were made to last forever; these figures embodied the deities, more than represented them. Artisans fitted their eyebrows and eyes in semiprecious stones to imbue them with life. Each day, the priests bathed, anointed, and dressed the statues, not unlike the ritual surrounding temple figures in India today.

It's very hard for us to imagine what their destruction would have felt like to the people of Ro-nefer.

When Artaxerxes and his soldiers swarmed from the river quays to raze the town, the destruction of the temple sent a terrible message. Armed with brutal iron short swords against sleepy civilians, the soldiers burst through the temple's huge double doors. Perhaps the priests on duty tried to fight or hide, but their own walls now trapped them. Down the stone pavement through the temple's center, deep into its heart, the soldiers swept toward the holy of holies and found Osiris, Amun, and other deities defenseless inside their shrines.

Seizing the statues, maybe the soldiers wrenched out semiprecious stones for themselves. Then they ran and set the gods ablaze. Perhaps they committed their iconoclasm on top of the wall, in sight of the citizens, and pushed the fragments over: we know someone in antiquity tossed the statues to the ground, since we discovered the wall's foundation trench just below the find spot. The conflagration fired the mud bricks red and brought them down over the remains, covering them for more than 2,000 years.

What might have taken place in the temple and the town disappeared beneath later occupation; the carnage that day passes from one frame of the filmstrip to the next. The temple was not just a religious center, but an

economic engine, a political machine, and an impressive target, perhaps with walls 10 meters tall or more, if it bore any likeness to examples at Luxor. Its destruction was one of many similar topplings as Artaxerxes III wrested away control of Egypt.

How a River Doomed a City

The Egyptians should have been better prepared for a river-borne invasion. But they'd thought they were safe for too long.

The reason why lies with the rhythms of the very river on whose annual inundation they depended. Hundreds of miles upstream, the monsoon rains caused the tributary Blue Nile and White Nile to swell, flooding the Nile proper, which deposited rich, nurturing silt onto the fields for several months each summer. Egypt became a nation-state of islands, on which its towns and people waited for the waters to recede.

On average, the Nile deposited a millimeter of silt across the entire floodplain per year—some years more, some years less—adding up to 1 meter every 1,000 years.[32] Close to the ancient capital of Memphis, near the apex of the Delta, the river split into seven branches with innumerable canals that fed into the Mediterranean. Here, the Nile dumped any silt not deposited along the floodplain, slowly adding landmass.

In time, the virtually impassable swampy landscape of the eastern Delta became livable, and small towns like Tebilla, inhabited since the Old Kingdom, could prosper and grow. If the swamps had remained, so would have Egypt's impenetrability, and Artaxerxes would have failed. However, when the Persian king sailed for Egypt, the country had been opened up to river transport. Ultimately, time and silt, gathering imperceptibly, allowed its conquest.

This story ends where it started: in space. Staring down at the Delta today, satellites reveal that only two of the seven Nile branches remain. Tell Tebilla is more than 60 kilometers inland from the Mediterranean, making it almost impossible to imagine the site along a large river connected to the Mediterranean. In fact, little of Tebilla is left, with more and more of the site being lost to modern encroachment and looting each year. So many other Delta sites face the same fate. Early visitors commented on mounds in the Delta as far as the eye could see, like anthills. Now, it is a half-hour drive or more between the remaining Tells.

Luck favored us when history recorded Artaxerxes III's destruction of Ro-nefer and when the CORONA imagery picked up a major feature on that site that later satellite data could not. Excavation added to the puzzle pieces, though our knowledge of Artaxerxes III's campaign will always be hazy.

With the destruction of sites around the world by climate change and urbanization, we must wonder how many puzzles have been lost entirely.

The good news is, with so many developments in satellite technologies, discoveries are being made more rapidly, across larger areas, and in places we never thought possible. Thousands of hidden stories are out there, about how past civilizations thrived, crashed, and were then reborn. To learn more about them, we first need to delve into how this field came into existence.

2

Space Archaeology

When first encountered, this may seem like a ludicrous, science-fictionalized name for a subfield of archaeology. It sounds like we hope to find evidence of an alien homestead on Mars, extraterrestrial arrowheads, or the mummies of little green men. While this would undoubtedly interest astrobiologists, the gaze of the space archaeologist turns back to Earth, via satellites.

The ground is an appropriate place to start, after all. Visions of gleaming white tents in the desert and scruffy teams kicking up the sand of millennia dance in the popular imagination. Modern archaeological fieldwork now requires pipettes and laser-scanning tools alongside the more traditional trowels and dustpans, but the romantic notion of archaeologists in the field is what first ignited my passion.

Excavating ancient sites is the best part of my job. My inner five-year-old screams with glee whenever I have the chance to use my Marshalltown, a brand of trowel. Every scrape on the ground carries the possibility of discovery. Think of the thrill of a lottery scratch-off game: there is a moment of anticipation, a quickening of the heart, and maybe a letdown. Now repeat 10,000 times a day. You never forget how you felt the first time you found something intact.

Digging for the First Time

In the summer of 1999, after my second year of university, I worked my first excavation at a site called Mendes, the ancient Per-Banebdjedet,[1] in Egypt's Delta three hours northeast of Cairo.[2] We spent most days toiling beneath a hazy ball of heat, exposing 3,000 years of history intermixed beneath an undulating expanse of earth. One moment we'd turn up burnished Predynastic sherds from 3000 BC, and Roman Period ceramics from 100 AD the next.[3] The unit where I worked dated to approximately 2200 BC, Dynasty 8, at the end of Egypt's first great Pyramid Age, the Old Kingdom.

Laboring in the stickiness of a Delta July, my Egyptian team and I had found the edge of a mud-brick mastaba, a classic rectangular tomb. Digging down, a

reddish ceramic circle slowly emerged, hints of an ancient vessel. Every second I wondered if what I'd found was going to be intact. As I dug around the pot, the struggle was to temper that enthusiasm, to measure, map, draw, and photograph the object in its original location before I moved it.

Cracks appeared in the pot, showing its broken pieces.

After half an hour of careful work, a 3-D jigsaw puzzle emerged of a flattened beer jar. A ghostly white slip coated its exterior. These jars, common in the Old Kingdom,[4] would not be out of place alongside the stylish serving options for mixed drinks on Bourbon Street in New Orleans. More than just an object, I had a possible story. Perhaps relatives of the deceased had brought the jar to the cemetery. They had said the ancient offering formula, a magical recital ensuring the dead received a bounty of bread, beer, and goods for eternity, and drank to their memory.[5] Looking closer, while brushing the pot for an official photograph, I saw something near its mouth: a fingerprint, from the potter who had made it 4,200 years ago.

In my imagination, the gulf of time separating us compressed.

The print seemed to be from a robust thumb. A middle-aged man appeared, sweat on his brow, bent over the wheel he rotated by hand. The ancient Day of the Dead, the Feast of Wagy,[6] was approaching, and he had a deadline to meet: he would need two sets of fine ware for the mayor and his family and 200 beer jars for the townspeople of Per-Banebdjedet.[7] Nearby, his sons stoked the kiln fires; too hot, and the pots would crack, too cool, and they would crumble. His daughter brought him a small cup filled with cool water, and he smiled, grateful for the blessing of the gods. Praise Djedet,[8] he would make his deadline!

Excavation's Greatest Challenge

Once you taste a drop like this from the spigot of history, you never forget, and your thirst is never quenched. Stories, not things, lie in disjointed sentences below the ground, and it is the job of archaeologists to coax them out and weave them into prose. But when facing a featureless sea of brown silt, or modern fields, or a mound beneath dense rainforest, the challenge is where to begin.

This is the exact question space archaeology has evolved to answer.

On most unexcavated archaeological sites, few hints exist aboveground of what features might be hidden below. This varies widely depending on where in the world you work. In Belize, towering mounds emerge from the rainforest floor, looking out of place in an otherwise gently rolling landscape and suggesting the presence of structures. Stone fragments may appear in straight lines beneath olive groves in Greece, showing the locations of 3,000-year-old walls. Archaeologists feel fortunate when they have these conspicuous clues to guide their excavation efforts.

When the clues are not so conspicuous, we have a setback. While archaeologists may live to dig, they cannot be in the field more than a few months each year, unless they work for a cultural resource management firm or as professional archaeologists for a cultural ministry. Even Indiana Jones taught class. Tight schedules and financial restrictions mean archaeologists must plan for every moment and penny spent: responsible publicly funded excavations do not want to report a fruitless season.

All applications for archaeological funding, public or private, now require well-formulated research questions, state-of-the-art project design, and evidence such as a preliminary site assessment that the team is digging on target.

Some sites are found by luck or by accident. In 1900, for instance, a donkey transporting a gentleman from a quarry in Alexandria, Egypt, fell into an abandoned shaft. What the poor donkey landed in were second-to-fourth-century AD Roman Period catacombs containing hundreds of individuals, now on the list of must-see tourist sites in Alexandria.[9]

Such sites underlie modern towns all over the world. When I was in graduate school, doing survey work in middle Egypt, I needed local help to verify hints from the satellite imagery that an ancient town might be lurking under modern urban landscapes. In the city of Dalga, the priests from a Coptic church led me down two flights of stairs to sacred rooms used for baptisms. They were decorated with sixth-century AD reliefs removed from the earliest Coptic church in the town, located some 20 feet below where we stood. No donkeys were harmed in the making of that little surprise.

Deny it though they might, most archaeologists pray to all gods ancient and modern who might heed our requests for success. It never hurts to spread the love, sample bags in hand! Aside from unexpected discoveries, archaeologists rely on diverse techniques to figure out what lies underfoot.

The simplest is fieldwalking. Moving along equally spaced lines, either in a group or alone, is a way to see how surface remains may change over a site or region. Sudden dense concentrations of slag, the by-product of metal production, may indicate an industrial zone. Tiny limestone chips and bone fragments found together could pinpoint a high-ranking cemetery, with the limestone pieces coming from sarcophagi or tomb structures. Larger limestone fragments in heaps, perhaps with inscribed and/or intact blocks, may locate a long-destroyed sacred or palatial building. And any ancient pottery or other remains flag the range of time periods below.

Fieldwalking—as well as ungulates—may represent an important step in site survey, but only an aerial perspective allows us to see the entire picture, not only of a single site, but of its relationship to the surrounding landscape. Aerial photos have proven invaluable for assessing ancient sites, and those taken from drones today are nothing less than spectacular. However, images from a far greater height, 200 miles higher than the International Space Station,[10] have paved the way for the subfield of archaeology that has already transformed our understanding of the past and of the potential for future discovery.

How Space Archaeology Works

Whenever archaeologists apply any form of air- or space-based data to the assessment of modern landscapes, attempting to locate long-buried rivers or hidden ancient sites, they are doing "space archaeology," also called "satellite archaeology" or "satellite remote sensing." NASA shoulders the ultimate name blame. In 2008, NASA began its "Space Archaeology" program,[11] funding scientists to apply satellite data sets to large-scale archaeological research projects. If NASA calls what I do space archaeology, who am I to disagree?

Interpreting satellite imagery is part science and part art. All remote-sensing specialists must start by learning the language of light, and it is not easy: what appears as a simple high-resolution photograph on your computer screen is so much more. Each pixel on the image is representative of an exact area on the ground.[12] The light composing the pixel represents not only the visible part of the light spectrum, but the near, middle, and far infrared, depending on the satellite-imaging system. Additionally, everything on the Earth's surface has its own distinct chemical signature that affects the light it reflects: much as we all have distinct signatures when we write our names, different materials show up uniquely in the light spectrum.[13]

For example, sand appears very different from forest on the satellite imagery. We can see this easily with our own eyes. When you need to discern different tree species *within* the forest, this is where chemical signatures come into play. A group of oak trees emits a different chemical signature than does a group of pine trees. Visually, they might appear as the same green to us, but using different parts of the infrared spectrum to visualize subtle vegetation health differences, we can perceive color variation.[14]

Remote-sensing specialists can exaggerate these differences by assigning "false color" to the images,[15] to highlight individual classes of surface features. Within remote-sensing programs (like Photoshop color replacement with an attitude), you can choose any color for any cluster of pixels. While it's recommended that users choose classes closely resembling their real-life counterparts—for example, green tones for vegetation, gray for buildings, brown for soils—you can choose any colors you want. Satellite images shown at conferences or in publications sometimes look like bad acid trips.[16]

Scientists shop for specific types of satellite images to suit the data they need. Each satellite is different, and there are over 1,700 of them up there.[17] Most are lower-resolution weather or large-scale satellites, with resolutions of 15 to 30 meters. These are the images most used, not just because they are free, but because there are millions of images going all the way back to 1972 that highlight short- and long-term landscape changes.[18] In addition to these free images, there are high-resolution images recorded by sensors such as DigitalGlobe's WorldView-3 and -4 satellites, with resolutions of between .31 and 1 meter, where a single pixel represents an area between the size of an iPad and a bodyboard.

Everyone looking at satellite imagery extracts pixel-based data to detect subtle short-term versus long-term changes, or to detect features. We tweak and test algorithms depending on our research questions, and eventually, through sheer dumb luck or a moment of genius, we find something of interest, usually because we're scraping the barrel bottom of possible techniques. When it turns out to be dried snot on our computer screen, this being science, we go back to the drawing board and try again.

It Isn't All "Aha" Moments, Except When It Is

People think that remote-sensing work is all about the "Aha" moment, the moment when a single click of a button reveals secrets hidden in plain sight. It isn't. A typical remote-sensing specialist will spend dozens of hours per week in

front of a computer screen, often cursing due to program crashes. When something does work, there is additional swearing, because you have forgotten to record the exact steps you took to reach that point. And you must start over. It's about learning, about refining the process.

Then again, "Aha" moments do happen. One of my favorite remote-sensing stories unfolded at the well-known Maya site of Caracol in Belize, which dates back over 1,000 years.[19] In 2008, a new laser-imaging technology called LIDAR, for LIght Detection And Ranging, was just warming up at the starting lines.

Diane and Arlen Chase, a gregarious and generous archaeologist couple at the University of Nevada, Las Vegas, had worked at the site for nearly 30 years.[20] When a keen biologist, John Weishampel, of the University of Central Florida, first asked the Chases about using LIDAR at Caracol, they told him that they were skeptical. They had never heard of it, but they were understandably enthusiastic about the idea of bringing more funding to their site. After decades of toil, they almost hoped they hadn't missed anything major.

They told him to go ahead with his grant application—he could try and peer beneath dense rainforest canopies using LIDAR if he wanted. It sounded like fun and wouldn't do anyone any harm.

John, now grant in hand, commissioned an airplane from the United States to collect the point cloud data, or hundreds of thousands of points from the top of the vegetation down to the forest floor, in a large area surrounding the site.[21] If you were to look at the area on Google Earth, all you would see is rainforest—a sea of green, with nothing suggesting anything ancient, aside from a few well-known limestone pyramids peeking through the tops of the trees.

After he had processed all the data, John displayed the images for Arlen and a small group. Arlen's exact words were: "Holy shit!" The same thing was on everyone's minds. Another astonished colleague said that this was the data to launch a hundred PhD dissertations.

The next day, Diane called John: "Arlen's been stuck to his screen all night looking at the images. And he's missed dinner and breakfast." In a single night, the entire field of Mesoamerican archaeology had changed permanently: Arlen had found more ancient Maya sites than he had in 30 years of combing the jungle. Today, he can find 500 new Maya features before lunch from his desk in Las Vegas.[22]

Such wholesale rethinking is not the product of a single flash of technical brilliance, but rather the result of decades of often serendipitous developments in the field of archaeology. To understand this takes a brief nosedive into the history of seeing ancient sites from afar.

It All Began with Balloons and Airplanes

Technically speaking, one of the first ancient sites to be viewed from an aerial platform was Stonehenge.[23] The famous Neolithic (ca. 2500 BC)[24] circular formation of large stones stands on a grassy down in southern England and is long beloved of modern pagans on summer solstice. Stationed near Stonehenge in 1906, Lieutenant Philip Henry Sharpe of the Royal Engineers' Balloon Section used a tethered balloon to take three photos of the site.[25] Published in the *Society of Antiquaries* shortly thereafter, the photos caused quite a stir.

Archaeologists could see the site and its relationship with the surrounding landscape, and curious darker patches appeared on the ground, suggestive of possible buried ancient features. A new world had been opened up from on high.

World War I saw the creation of the Royal Flying Corps, with pioneering aviators flying across Europe and the Middle East. Used for establishing artillery ranges and the enemy's positions, their aerial photography efforts formed the crux of their operations.[26] Photos of the front used to plan attacks have become essential archaeological data today.[27]

Later, Father Antoine Poidebard, who had the rather fabulous nickname of "the Flying Priest,"[28] flew a biplane across large swaths of Syria and Lebanon from 1925 to 1932, recording many ancient sites from above.[29] Aside from these invaluable early photos, he created the foundations for aerial archaeology in the Middle East, emphasizing the importance of timing for revealing ancient structures clearly. Images taken in the morning, for example, when the ground contained more moisture, revealed more sites than those taken in the afternoon, when the drier ground had more uniform colors.

Meanwhile, in England, Osbert Guy Stanhope Crawford, better known as O. G. S. Crawford, pioneered the application of aerial photography to long-occupied landscapes. After serving in the Royal Flying Corps during World War I, he joined the Ordnance Survey as an archaeological officer.[30] While a prisoner of war in Germany during World War I, he had completed *Man and His Past*, a seminal volume emphasizing the importance of maps to define culture.[31] Affectionately called Uncle Ogs by the rising generation of British archaeologists,[32] Crawford located hundreds of previously unknown sites across the United Kingdom.[33] Even today, his aerial photographic archive of Britain remains an invaluable resource for archaeologists.[34]

Crop Marks—It's Not Just Aliens

Most features show up on these early aerial photographs, and later on satellite images, as crop marks. Crop marks do what the name says: vegetation grows faster, slower, or, in some cases, not at all, based on what is beneath the ground, revealing possible buried walls or even entire buildings.[35]

Let's break that down. Imagine the foundations of a stone wall, slowly covered by earth over time. As grass takes root over the top, its roots simply cannot go as deep as the grass a few feet away. Growth becomes stunted and it is less healthy than the other grass. In a time of drought, it might die altogether.

Conversely, over time, a ditch fills in with rotting vegetation. This forms fertile mulch and is an ideal place for new vegetation to grow. Grass and other crops thrive, growing taller and healthier over the ditch than the surrounding area.

The shadows formed by the taller or shorter vegetation can easily be seen on aerial photos, while more subtle differences in vegetation health can be picked up by satellites recording information in the near infrared. Chlorophyll content, for instance, can best be seen in the near infrared—in which all vegetation appears red.[36] Try explaining it that way to your child the next time they ask you why grass is green. My son's response was: "You're a weirdo, Mommy."

These crop marks have a fascinating history, and people can actually see them while walking across fields. In Britain, observant walkers mentioned them over 500 years ago, as noted by British antiquarian William Camden, who named them "St. Augustine's Cross" after the earliest missionary to England.[37]

I regularly receive emails from people in Europe who send me snapshots of crop marks that they have observed on Google Earth, and I am usually impressed. People have great eyes. Straight lines rarely occur in nature, and it is even rarer for them to form rectilinear features, so when multiple connected boxes show up on a satellite image of a field in Britain, France, or Italy, there is a high degree of probability you have discovered a Roman house.[38] Even when a field has been plowed over for millennia, the stone foundations survive and affect crop growth. Despite the pub lunch at the finish line, I can no longer idly go on pleasant Sunday rambles across these fields in England. I'm always on the lookout, just in case.

From World War II to the Start of the Space Age

Following World War II, remote-sensing technologies underwent a great revolution as archaeologists and other scientists recognized the value of emerging color and infrared technologies. In fact, my grandfather, Professor Harold Young, wrote in a 1950 publication: "In a relative sense, the use of aerial photos in forestry has only reached an early adolescent stage. Many research workers are trying to determine the limits of aerial photos, as well as the many ways that aerial photos can be profitably used. Today the possibilities of color film are scarcely known at all."[39]

This was only 70 years ago. Now, we can 3-D scan objects and take thermal infrared photos on sites using our cell phones.[40] These technologies have emerged over only two generations—a blink of the eye of our human history.

During my grandfather's era, archaeologists could access thousands of military images of Europe and the Middle East and use them to plan new surveys. Aerial photography had become a standard archaeological tool, led by pioneers like J. K. St Joseph of Cambridge University. Trained as a geologist, St Joseph learned about the field of aerial photography during World War II, when he served in the Ministry of Aircraft Production. After the war, he commenced major photography of landscapes around the United Kingdom via Royal Air Force training flights, leaving over 300,000 photographs to Cambridge University. He gave wonderful lectures with amazing images but spoke in such a way to earn the nickname "Holy Jo."[41] That's one way to preach from on high.

Expanding interest such as this led to the first international colloquium on aerial photography in 1963,[42] and he published a key tome, *The Uses of Air Photography*, in 1966.[43] With the advent of new military rocket programs, archaeologists could set their sights higher, to spy, in every sense of the word, on the old and the new.

The space race had unintended consequences for archaeologists today. Developed in the 1950s, CORONA, LANYARD, and ARGON were top-secret government spy satellite programs that mapped Russian activities during the Cold War. From 1960 to 1972, rockets launched camera systems into space, capturing large areas of the Earth's surface and producing high-resolution

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