AUGUAS ZARCAS, AN UNUSUAL METEORITE, MAY HOLD THE BUILDING BLOCKS OF LIFE.

A Meteorite Worth More than Gold

Aguas Zarcas

BY **JOSHUA SOKOL** AND **ANDREA SOLANO BENAVIDES**

AS THE FIERY EMISSARY streaked across the skies of Costa Rica, an unearthly mix of orange and green, Marcia Campos Muñoz was in her pajamas, watching TV on the couch. It was 23 April 2019, a bit past 9 p.m., when she heard a foreboding rumble. Heart racing, she tiptoed outside to calm her barking dog, Perry, and to check on the cow pastures ringing her small house in Aguas Zarcas, a village carved out of Costa Rica's tropical rainforest. Nothing. She ducked back inside, just before a blast on the back terrace rattled the house to its bones.

Campos Muñoz phoned her father, brother, and oldest son, who rushed to the house. On the terrace, they found a grapefruit-size hole in the corrugated zinc roof and a smashed-up plastic table, last used for the quinceañera of Campos Muñoz's daughter. The culprit was scattered on the floor, in pieces as black as coal.

She picked up the biggest fragment, still warm to the touch. Already, her phone was chiming with WhatsApp messages from friends telling of blazing fireballs and rocks raining down on farms and fields. The family added its own viral messages to the mix: photos of Campos Muñoz and her son holding the big stone that crashed through her roof. Within hours, a local journalist visited the house and streamed videos of the damage on Facebook Live.

Marcia Campos Muñoz held off selling her largest meteorite chunk, even as its value surpassed that of gold. Photo by Andrea Solano Benavidas.

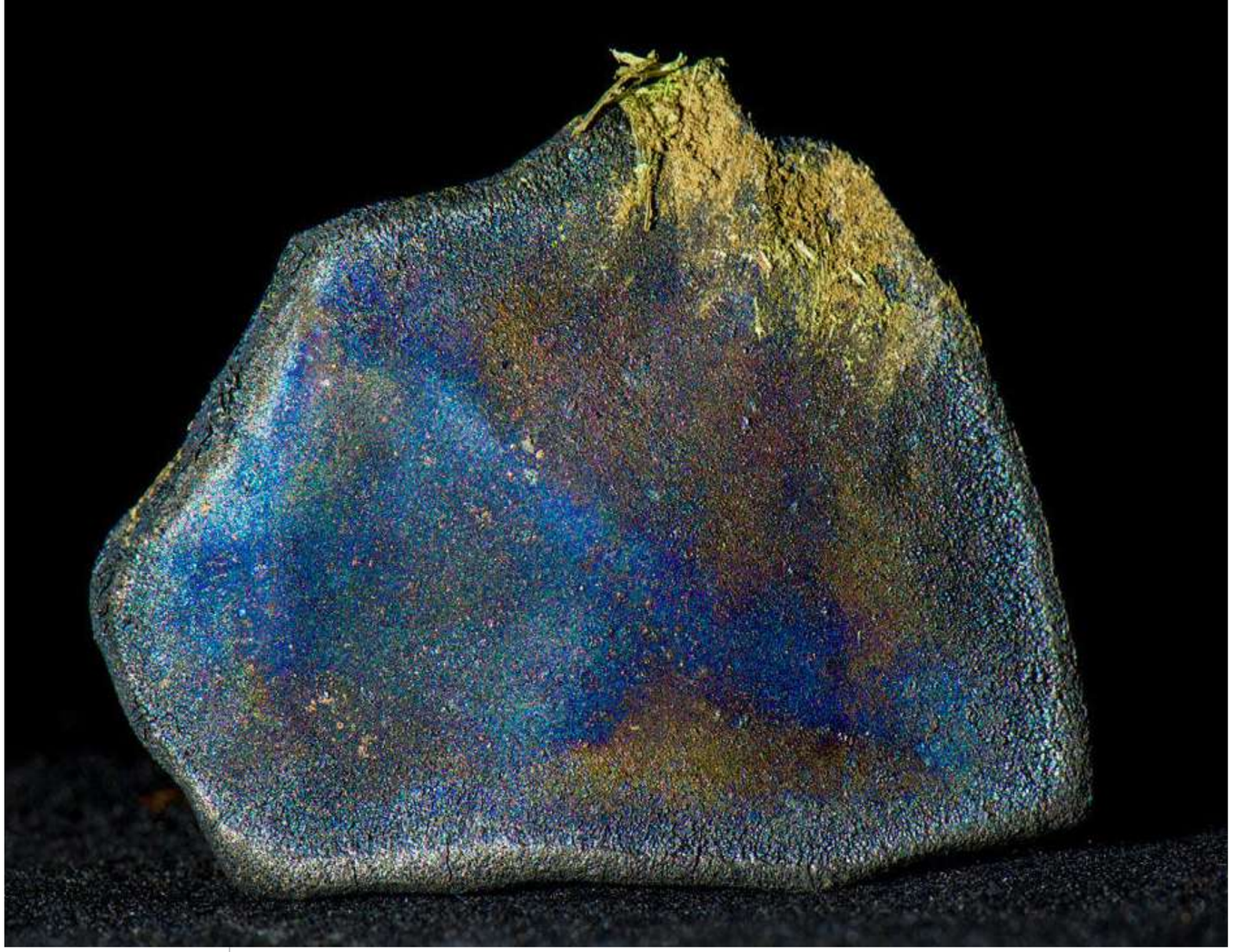
It was only the beginning. A space rock the size of a washing machine had broken up in the skies over the village, and the excitement was about to spread globally.

Meteorites are not uncommon: Every year, tens of thousands survive the plunge through Earth's atmosphere. More than 60,000 have been found and classified by scientists. But meteorite falls, witnessed strikes that take their name from where they land, are rare—just 1196 have been documented. And even among that exclusive group, there was something extraordinary about this particular meteorite, something anyone with the right knowledge could know from the first pictures. The dull stone was, as far as rocks go, practically alive.

Aguas Zarcas, as the fragments would soon collectively be called, is a carbonaceous chondrite, a pristine remnant of the early Solar System. The vast majority of meteorites are lumps of stone or metal. But true to their name, carbonaceous chondrites are rich in carbon—and not just boring, inorganic carbon, but also organic molecules as complex as amino acids, the building blocks of proteins. They illustrate how chemical reactions in space give rise to complex precursors for life; some scientists even believe rocks like Aguas Zarcas gave life a nudge when they crashed into a barren Earth 4.5 billion years ago.

FROM THE BEGINNING, the inky Aguas Zarcas resembled a legendary carbonaceous chondrite that exploded in 1969 over Murchison, an Australian cattle town. Geology students helped collect about 100 kilograms of Murchison, and a local postmaster mailed pieces of it to labs across the world. To date, scientists have recognized nearly 100 different amino acids in it, many used by organisms on Earth and many others rare or nonexistent in known life. Hundreds more amino acids have been inferred but not yet identified.

Murchison also contained nucleobases, the building blocks of genetic molecules such as RNA, and in November 2019, researchers found a major component of RNA's backbone: the sugar molecule ribose. This half-century parade of discoveries jump-started



Clays in a 44-millimeter-wide Aguas Zarcas fragment may hold amino acids, along with stardust that predates the Sun. This piece is held at the Laurence Garvie/Center for Meteorite Studies/Arizona State University.

the now-flourishing field of astrobiology. "We're not detecting life itself, but the components are all there," says Daniel Glavin, an astrobiologist at NASA's Goddard Space Flight Center. "I wouldn't have a job without Murchison."

The 30 kilograms of primordial leftovers from Aguas Zarcas hold similar promise. But these new pieces are 50 years fresher than Murchison, allowing scientists to apply modern techniques to preserve and probe what amounts to fragile lumps of unspeakably old clay. They could sniff out delicate organic compounds long evaporated from Murchison. They could hunt not just for amino acids and sugars, but also proteins, which have long been suspected but never confirmed in a meteorite. And if they were clean and careful, they could hedge against a perennial criticism of the Murchison finds by ensuring the molecules discovered inside were native, and not contamination from Earth's own microbes.

"If I had to start a new museum collection for meteorites, and I could only select two, I would choose Murchison and Aguas Zarcas," says Philipp Heck, who curates the meteorite collection at Chicago's Field Museum. "If I could choose only one, I would choose Aguas Zarcas."

FROM THE INSTANT the rock entered the atmosphere, however, the clock began to tick. Clays—its major constituent—soak up surrounding air and water like a sponge; earthly amino acids and other organic compounds intrude, layer by layer, followed by the microbes that produced them. Each second in contact with moist rainforest soil or human hands destroys more information. "Ideally we pluck it from the air while it's coming down," says Ashley King, a planetary scientist at London's Natural History Museum, "whilst wearing gloves."

For billions of years, Aguas Zarcas had avoided such contaminating influences. If it could stay that way just a little longer, scientists would be able to recover information from three ancient, otherwise inaccessible periods.

The first predates the Solar System. Some 7 billion or 8 billion years ago, specks of stardust were ejected from supernovae and the outer atmospheres of aging stars, some made of hardy materials such as graphite, diamond, and silicon carbide. The size of smoke particles, they drifted in space, settling in a nameless interstellar cloud.

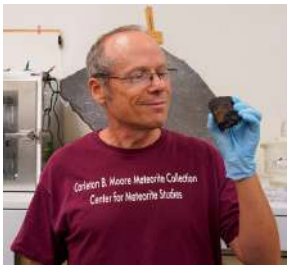
In the next phase, that formless cloud collapsed into a disk swirling around the newborn Sun, generating frictional heat that roasted everything but those presolar grains into a seething vapor. As the disk cooled, the first solids condensed out like frost on a windowpane: crystalline clumps of aluminium and calcium as big as poppy seeds. These fragments date back 4.56 billion years, defining the age of the Solar System. Within a few million years, molten drops of rock cooled into glassy spheres—the "chondrules" that give chondrites their name.

Then, in the third phase, these small particles started to stick together into boulders, among them the hodgepodge of rocks that would become Aguas Zarcas. Planets began to sweep them up, but the future meteorite avoided that fate, remaining part of a small asteroid in the cold void beyond Jupiter. In that early home, it avoided being melted by the Sun or in the hot interior of a planet.

Instead the asteroid grew modestly, amassing specks of ice and carbon, the latter already morphing as sunlight drove chemical reactions. In its interior, the presolar stardust, the first solid minerals, the glassy spheres, and the carbon compounds all crowded together. Heat from the radioactive aluminum melted the ices. Liquid water gushed out, kicking off another wave of chemistry that would go on for a few million years more. Simple compounds such as hydrogen cyanide and ammonia dissolved and were transformed into amino acids and other complex forms.

> "If I could choose only one, I would choose Aguas Zarcas."

Many carbonaceous chondrites crashed into early Earth, perhaps delivering not just a sprinkling of organics, but also a portion of the planet's inventory of water. Aguas Zarcas itself endured several billion more years of solitude, save for occasional smash-ups with other wayward space rocks. Based on its fiery trajectory through Earth's atmosphere, caught on dashcams and volcano-monitoring cameras,



Laurence Garvie, meteorite curator at Arizona State University, Tempe, examines a fragment that punctured a doghouse.

Mike Farmer, the dealer who sold the fragment to Garvie (above). He also bought the doghouse.

researchers believe the unknown body ended up in the asteroid belt between Mars and Jupiter. Then one last collision splintered off a chunk, which spiraled in toward Earth, nearing the rotating globe just as Costa Rica spun into view on 23 April 2019.

Surviving its passage through the atmosphere was one test, but now another threat loomed: the country's formidable rainy season, which could erode and contaminate much of that preserved history. The most important meteorite in half a century had landed on one of the last dry nights of the year. Nobody knew it then, but the first hard rain was 5 days away.

ON 24 APRIL 2019, the day after the Aguas Zarcas fall, meteorite dealer Mike Farmer wasn't planning on doing much, maybe relaxing with his son or doing some yardwork outside his house in a Tucson, Arizona, gated community. His bags were already packed for a flight the next day to hunt for a meteorite that fell in Cuba. But soon after he woke up, the Facebook picture from Campos Muñoz flashed across his screen. "It was like, oh, Jesus Christ," he says. "I knew immediately what it was." So much for Cuba.

He quickly packed $50,000 in cash into the liner pockets of a safari vest, along with more clothes for what would now be a jungle expedition, and got on the first possible flight to Costa Rica. As the plane taxied for takeoff after a layover in Dallas, Farmer's phone dinged. It was another message from Costa Rica with a photo. Would he like to buy some meteorites? "I about had a heart attack," Farmer says.

That message came from the family of Ronald Pérez Huertas, who lives a few kilometres from Campos Muñoz outside of the village of La Palmera. On the night of the fall, Pérez Huertas was leaving his job at a cheese factory when the fireball flashed overhead. At home, his wife, Virginia Argüello Arias, heard a sound like thunder—the sonic booms of the atmospheric breakup. When she looked outside, the neighbor's German shepherd, Rocky, was cowering and trembling. Later, they learned that a fragment had crashed through Rocky's doghouse.

The next morning, Argüello Arias walked to her front gate. She spotted a small stone coated in an iridescent sheen: the fusion crust that forms in the heat of descent. That afternoon, her son and daughters joined in a family hunt through pastures and stands of mango and soursop trees. They found enough fragments to cover a table and snap a tempting photo. After Googling meteorite dealers, they sent the photo to someone they thought might be willing to pay. To their amazement, he was already en route.

The following morning Farmer showed up in person, along with Robert Ward, a competitor and sometimes collaborator in the meteorite business who had arrived on the same flight. Counting out cash, they bought those initial stones—much too cheaply, the family now realizes.

Farmer also bought the fragment that hit Rocky's doghouse. And, for good measure, the doghouse, too. For the next 4 days Farmer and Ward bunked together at a nearby coffee plantation and set up shop each day on the family's front lawn, offering to do business with anyone in town who trekked over...

...CAMPOS MUÑOZ is still a holdout, maybe the last. She still has the big chunk that fell through her roof, which she hopes will end up in an exhibition. She wants more for it—she won't say exactly how much—than dealers have offered.

The hole in the roof remains. She had meant to fix it, but first came the meteorite hunting frenzy, then the rainy season, and now the pandemic. Plus, she knows these bits of collateral damage are valuable to collectors, too. "This hole in the roof and the damaged tables are part of our family now," she says.

Neighbors suspect her family are all millionaires, winners of a cosmic lottery, she says. Strangers still show up from time to time and dawdle out front, looking for the "house of the meteorite." She stays in touch with the Costa Rican scientists to follow their research and reads every paper they send her way.

"I feel very proud that such an important event for history and science took place in my country," she says, "and in my house." □

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