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On the Phase Transitions of Methane Hydrates

One of the grad assistants, Jim, had left the mail, a thick stack of weathered, manhandled envelopes bearing the nicks and scars of U.S. Postal Service transportation, in a pile by the lab's primary computer. The first one Tony Peitrus opened was a confirmation letter from the American Geophysical Society for an appearance at the annual AGS conference to present initial research findings. He set this aside as a "Jim job." The second envelope would change the way Tony felt about the world. He never got around to the rest of the day's mail.

He opened the letter with his eyes diverted, still on the computer screen, lunch settling in his stomach and his dad's advice—"Grants can't read denser than the actual science"—still irritating him, an absent mental rash. He'd often do some of his best professional thinking while playing with his daughters or making love to Gail, so he'd saved this moment all day, hoping that to idle on one quandary would somehow unlock the other. Reading over the results of the model cross-stitched onto the screen in an aggressively rote black and white spreadsheet of raw, cluttered integers, his eyes tried to grasp the gist of this latest round of data without diving too deeply into the morass. There'd be time for that later, and he always found himself compelled by each data set much the way his kids might anticipate a lesser holiday, like an Easter. It wasn't Christmas, but hell, you did get a basket full of chocolate, and he ached to tear into it. He would let the question of his vanishing NSF funds and failure thus far to secure another grant absently nag at him. As if competing for money, lab space, and computational resources at Scripps wasn't already pain enough in the ass, he and Niko had no "charismatic megafauna" (his wife's designation) involved. Only the maddening mystery of methane hydrate phase transitions.

To him, as to any scientific board with working brain cells, the obviousness of studying deep-sea methane molecules felt like a bright red elephant walking down La Jolla Shores Drive. But explaining it to the layperson required a convoluted story, especially as to why it deserved to take money from the vanishing schools of tuna or adorable chirping dolphins. It began with the model his eyes crept over now: he and his fellow researcher, Niko, had concocted what they thought was a rather ingenious Monte Carlo simulation to predict the behavior of clathrates under changing conditions of temperature and pressure. He and Niko

spent so much time in the labs carefully playing with the input parameters that they sometimes forgot this could all sound unbearably tedious and impossible to grasp. Gail had always attempted to put her molten, poetic mind to work, to coach him into making the clathrates' story as cogent as possible with patience and the occasional restaurant napkin diagram. Their youngest, Catherine, had spent the last few weeks at dinner grouching more than usual. "I'm *bored*. Stop talking about this," she said while smushing her face in her hands.

"So you're trying to figure out when some ice will melt," Gail had said, throwing one of her toying winks, the oak-colored left eye expertly blinking across their dinner table while the right remained fixed on him.

"Ah. Ice, the evil misnomer," he said, stabbing at Gail's chicken. "Before we can even get a word on a piece of paper some a-hole porpoise guy needs to drop a few hundred grand on new sonar equipment to measure dolphin clicks."

"I know what that word means, Daddy," said Older One, Holly, her expression genuinely distressed.

Gail shook her head and flared her nostrils dramatically. "Boy, what I wouldn't give to watch those porpoise researchers burn in hell, huh?"

No stranger to the politics of academic research, his dad had spent a few hours on the phone with him trying to make him talk through the story. Tony and Niko studied molecular interactions, specifically the ones that governed the phase transitions from an ordered state to a disordered state. The most obvious example and the one they were most interested in was nature's random perturbations influencing the collective behavior of molecules that might turn a solid into a liquid. Warmer temperatures were obviously one variable that could trigger the abrupt transition from ordered to disordered states: solid to liquid, liquid to gas. The Monte Carlo method—so named because Stanislaw Ulam compared it to random dice rolls—allowed scientists, economists, and mathematicians to perform all kinds of experiments to model phenomena that have wide uncertainty for their inputs. His dad, a college math professor for forty years, had been unable to resist reciting the history lesson: Ulam had actually been looking at the chances of success for the chain reaction needed to successfully detonate an A-bomb. "Innocuous names for hyper-violent ends, which then somehow create extremely useful means are a staple of intellectual discovery," his dad lectured in that runaway ruminative way of his. The clathrates littering the floors of the world's oceans, some of them 5,000 feet deep, were just such a phenomenon. He, Niko, and their team of grad assistants spent their days running these computational algorithms millions of times over,

constantly adjusting variables including but not limited to temperature and pressure (though they had nearly a thousand variables in play for some models, most were related to those two fundamental categories). The idea was to mimic the random real-world fluctuations of molecular behavior. A scattershot career that began in theoretical physics but had taken Tony to Yale where he ended up in the Department of Geology and Geophysics doing coursework in everything from fluid dynamics to statistical analysis methods before finally developing a more permanent interest in oceanography, had been like boot camp for this research. Physics, he'd come to understand in New Haven, was a good way to spend one's career in the scrum of pompous nimrods and preening braggarts. In oceanography and the crisp salt air of Scripps's beachside campus, he'd found a way to apply his meticulous theoretical imagination to hard earth sciences. He spent a fair amount of time sunburning on the beaches of La Jolla with his girls, and perhaps a bit more obsessing over the pore width and cage structures of clathrates. He'd ponder the space group symmetry and the lattice constant for the simulated hydrate crystals while showing a four-year-old how to build a better sand castle.

When he picked up the tan nine-by-eleven envelope, his eyes left the screen only momentarily to catch a glimpse of the handwritten address, his name at the top in neat block letters, SCRIPPS INSTITUTE OF OCEANOGRAPHY beneath it. It felt light, maybe only a slice or two of paper inside.

Bacterial degradation of organic matter in the oceans produced methane, he'd told his dad. Basically, plants and animals that rotted in a low oxygen environment (usually because they were buried under sediment) became trapped in crystals of frozen water. Thus you got all sorts of idiots referring to the stuff as "methane ice." Even science writers were fond of that term, likely because they thought explaining the physical world to the layperson required condescension. But the methane wasn't frozen; it was just trapped inside a lattice-like matrix of ice. It took thousands of years for methanogenic bacteria and sediment to do their work and trap the methane molecules where the temperature and pressure allowed, either in the Arctic permafrost, beneath the sea floor, or on the surface in frozen chunks clutching the rock. Every gas hydrate had a similar structure, but methane was the most prolific prisoner, and in some places it was a prominent feature of deep-sea ecosystems, which first drove the interest at Scripps. When he applied as a postdoctoral researcher, several faculty had pointed him to Nikolaos Stubos, the Greek wunderkind from UC Berkeley, who had similar areas of interest. They'd finally gone from colleagues to friends when that NSF

grant had come through. Together they began plotting how to best understand the strange combination of circumstances that allowed for the formation and enduring stability of this particular hydrate. Together they'd watched the 2010 BP oil spill with no small dose of glee as their research subject got the equivalent of a Hollywood close-up. One of the first schemes BP scientists employed to stop or slow the well spewing oil into the Gulf of Mexico from 5,000 feet below the surface was a "containment dome." The idea was to lower this massive dome to collect the oil and eventually cap the well, but as the dome descended through the water's depths it began to clog and choke with the accumulating hydrates forming as methane spewed from the breach. The plan had to be abandoned. It was the first time virtually any reporters or the public had even heard of the chemical compound, and he and Niko had to suffer through endless mischaracterizations of their research subject, from the obnoxious "methane ice" to the downright vacuous "ice crystals." Niko, in that hard-edged Greek accent, displayed open mystification that journalists could provide such inaccurate information, while Tony scoffed that given the general state of science education, it was surprising they'd showed up at the right ocean. Lately, methane hydrates had been resurfacing in the news because the oil and gas industry had grown increasingly bullish on the prospect of developing hydrates into a fuel source. Estimates always varied, but in the sediments considered part of U.S. ocean territory alone there was thought to be roughly a 1,000-year supply of natural gas, though developing those resources was another question entirely. In 2013, Japan became the first country in the world to successfully extract natural gas from undersea methane hydrates forty miles from their shore in the Nankai Trough using a depressurization method. The rest of the energy world was watching eagerly because of the speculated abundance of this particular resource.

"Why don't you guys just go get some of that sweet, sweet petroleum money?" asked Gail after he told her the news from Nankai. "Isn't that how almost all geologists get funded?"

Most days they met for lunch at a Panera near campus. He'd routinely show up late and find her curled into the same sofa chair, eyes poring over whatever lit crit text she was abusing for her doctorate.

He grinned. "Turns out our work kind of puts us at odds with the predilections of the extraction interests."

"Wait, Tone, are you—" Her eyes widened. "Are you telling me oil companies don't want to sponsor sound science—what? Wait. This changes everything. Get the girls out of Exxon-Mobil Little Tots Academy right now." He snickered at this. She was his wife, but she was

also the goofy kindergarten best friend who always got you in trouble by shooting milk through her nose.

The return address did not pierce his concentration other than the “Louisville, KY” because he absently recalled that Scripps sometimes bought lab equipment from a manufacturer in Kentucky (Or was it Tennessee? That part of the country all felt approximately the same, as he rarely ventured into the vast interior of the nation except to switch planes at O’Hare every now and then).

However he built his explanation, he always found himself detouring into the work of his pen pals in Melbourne—a team of researchers attempting to create a more precise estimate of the ocean’s total reserves. The distribution of methane hydrates in the world’s oceans caused a headache for scientists because the field data was so spotty, though there were some assumptions. The largest reservoirs of methane hydrates could be found on continental shelves in the hundreds of meters of sediment closest to the surface of the sea floor. There was also a small amount in continental tundra. To find marine hydrates you had to scour coastal zones with high biological production. You needed the steady, slow, sifting rain of organic material falling to the ocean floor so that when it degraded in the required low-oxygen environment, it would produce methane and get trapped if the conditions of pressure and temperature were right. Given this, a map of deposits looked like a ring around the continents, as if a teacher told Catherine to outline the land masses in crayon. Off the East Siberian continental shelf alone lay an estimated 1,400 billion tons. In other words, the stuff was everywhere. There was also a great deal of historical evidence that hydrates were more prevalent now than at almost any other time in Earth’s history. Because the earth had experienced a rather temperate climate over the last few tens of millions of years, biological matter continued to form methane, freeze, and accumulate uninterrupted by the planet’s periodic bursts of heat. Niko, in that assertive, unflappable (“a smidge chauvinist,” according to Gail) Greek way of his never got tired of pointing out that the study of “how much” was the business of those petroleum geologists, not real scientists. Their only concern was “how warm.” He and Niko spent years mining clues from the Paleocene-Eocene Thermal Maximum, which Tony now referred to as the “Pet’em” because of Holly. In her heroic efforts to teach herself to read ahead of schedule, Holly had seen a book Tony was reading on the subject, which had used the common acronym “PETM.” She’d asked, “What’s a Pet’em?” He explained the Pet’em was the far less famous extinction event, a red-headed step-child to the die-off that inspired *Jurassic Park* and the rest of

pop culture for little boys (Tony had read that novel so many times as a kid that he'd gone through three copies of it, the depth of the science feeling positively pornographic).

"To understand the Pet'em," he told her. "It's instructive to look at the end-Permian extinction."

"What's a red-head stop-child?" she asked.

It proved more difficult to explain this to a six-year-old than the end-Permian, the event that nearly wiped all life off the face of the planet. For the longest time scientists understood that a million years' worth of volcanic eruptions in Siberia were the likely culprit, but the math didn't add up. The volcanoes simply couldn't have produced enough carbon dioxide quickly enough to raise the earth's temperature six degrees Celsius. So some clever researchers began doing carbon isotope studies, trying to figure out how to account for all the light carbon found in rocks from the end-Permian. It was like the entire goddamn planet's supply of coal had suddenly oxidized right into the atmosphere, but there weren't a lot of coal-burning creatures running around back then, mostly just fish and bugs. Yet that light carbon was the reason 96 percent of life in the water and 70 percent of the land-based variety were wiped out almost overnight in geologic terms, clearing the plate for the dinosaurs. There remained only one desperado that could plausibly hold enough light carbon to explain the end-Permian extinction: the melting of methane hydrates. A liter of hydrate expands into 160 liters of methane gas, which acts as a powerful greenhouse gas for a decade or two until it oxidizes into carbon dioxide and remains in the atmosphere for centuries as part of the carbon cycle. This explanation allowed the math to add up. Then, approximately 55 million years ago, came the Pet'em, a more minor extinction event than either the end-Permian or the meteor that wiped out the dinosaurs. Yet the Pet'em certainly mattered to quite a few marine species that didn't make it. The earth experienced a rapid heating of five to six degrees Celsius in only 20,000 years. When you looked at sediments deposited during the Pet'em, you saw a massive spike in light carbon, which meant that something injected over 3,000 gigatons of carbon in two quick bursts that each only took a couple thousand years.

The only explanation for this was a rapid melting of undersea methane hydrates.

Tony pinched open the metal clasp of the envelope and slid a finger beneath the fold to give it one quick, ineffectual tear that simply created a small flap of paper. Nevertheless, it was an opening for his finger to work with as he continued to study the data.

“Twice we know the hydrates melted,” he told his dad on the phone call. “And twice there were widespread extinction events.”

So the question then became what caused the hydrates to melt in the first place? By looking at other PETM-like events in the Paleocene and Jurassic eras—and coupled with the end-Permian hypotheses—other scientists had firmly established that the melting hydrates were not due to some outside trigger, like a meteor strike, but rather an unambiguous feedback. When the earth warmed up during climate oscillations caused by solar activity, widespread volcanic eruptions, or perturbations in the earth’s orbit, at a certain point the methane release occurred, spiking CH₄ and CO₂ levels in the atmosphere and raising the temperature further. The best theory for how that worked involved ocean circulation: during the Pet’em, warmer, saltier water began flowing to the deep oceans, which in all likelihood began melting the top surface of the hydrates. This exposed deeper reservoirs of hydrates, which in turn melted, exposing more. Why ocean circulation changed during these periods was still largely a mystery, but you didn’t need a doctorate from Yale to guess that the three-degree Celsius rise in global average temperature prior to the Pet’em probably had something to do with it. Luckily, it only took a little over 100,000 years for the carbon cycle to return that excess carbon to the earth, so the mammals of the day could get on with their humping and eventually produce humans. That summer he’d found himself on a Gulf Coast beach going a bit mad trying to explain why this mattered to Gail’s obnoxious talk-radio-obsessed younger brother, Cory, who frequently directed his snide country-club snark toward Tony’s “mind-and-dick-numbing” job. Cory reminded him of the meathead kids from back in his Amherst high school, who verbally tormented him and his friends (as if during adolescence Tony ever forgot he was pale and skinny with cheek-scarring acne and large pink lips that never lost that chapped, cracked-desert look). Cory was an adult version of those guys, only with a cushy job at his father’s pesticide business and therefore access to the family vault. Tony’s face grew hot with sun and frustration as he attempted to explain that given humanity’s little science experiment of pumping all the carbon it could find into the atmosphere about ten times faster than during the PETM, it was probably worth figuring out how soon the goddamn methane hydrates might melt and turn Cory’s Sarasota beachfront condo into a pretty fucking shitty investment.

Gail shot him a look over the top of her sunglasses that said *Play nice*, and he again wondered how she’d come out of this dynastic, self-obsessed Floridian family.

He was somewhere here—tugging and pulling among the numbers from the latest simulation, memories of their last trip to Florida and his brother-in-law, whom he only tolerated because Gail made fun of Cory and his anorexic wife behind their backs even while affirming a genuine and fierce protective affection for him, anticipation of the next time they might visit Sarasota, if only because the girls loved it, and the thought that this weekend Catherine, whom he always called “Khaleesi” after the brave but stubborn character from his favorite book series, would turn five years old, which seemed impossible, as it felt like the blink of an eye since she’d come along and he’d told three-year-old Holly, “You are a big sister now. You must look out for the younger one at all costs. I hereby dub thee ‘Older One,’” and patted her on each shoulder using a cardboard wrapping paper tube as a makeshift sword as she knelt before him and Gail filmed with her iPhone—when two things happened at once.

First, he aggregated what he’d read on the screen. It sunk in the way a striking paragraph of George R.R. Martin prose could when he killed off a major character. Second, he chose that instant to turn his full attention to the envelope, which he succeeded in opening by running his index finger through the paper as an impromptu letter opener. There was only one sheet of paper inside, and he pulled it out. The big block letters were similar to those on the address.

AFTER THIS YOU AND YOUR PEERS COLLUSION WILL BE EXPOSED AND YOU’LL BE CHARGED WITH THE GREATEST FRAUD EVER PERPETRATED IN THIS CENTURY. YOU ALL WILL BE EXPOSED AND DISCOVERED BUT I FEAR EVEN THIS ISN’T ENOUGH PUNISHMENT FOR WHAT YOU DESERVE.

He snorted a laugh at the missing apostrophe in “youll.”

Gail often joked that he’d been born a cantankerous old bastard even when they’d first started dating in their late twenties, yet how could you not go through life without a sense of contempt for the sheer, uninhibited volumes of stupidity displayed by most people? This was a first for him. He’d certainly heard of other scientists receiving crass and intimidating notes from the cornucopia of right-wing or conspiratorially minded agitators who seemed to take up all the oxygen on the internet. He’d heard of a few Scripps colleagues who’d turned over e-mails to the police when the language verged on threatening. Through the Melbourne folks, he knew of a researcher in Sydney who studied clouds and who, during that country’s debate on a carbon-pricing scheme, had

received such odious threats that she got a security detail for a brief period. “A goddamn cloud scientist,” he told Gail. “A goddamn woman whose job is to look at clouds all day.”

Tony stayed out of all that, though. He hated politics and hated the nutjobs who surrounded the whole business. As far as he was concerned, all this fury directed at people only concerned with taking passionless, unbiased measurements of phenomena and using those measurements to make informed guesses about the state of reality was nothing more than the sad hobby of frustrated losers ranting into the ether. And here was his first introduction to the field of crank pen pals, although he supposed once he put his name on a few more papers, more letters would follow. Gail would want him to take this to the police. While carefully phrased to not be a death threat per se, the substance certainly had enough innuendo in that direction. Never one for overreaction, though, Gail’s voice sounded off in his head. He could almost hear her making an icy joke. Something like, “At least this balances out all the bras and panties you usually get” (although Gail was funnier than that). What had his dad once said about his mom? “Number one, find a woman with a sense of humor. There is no number two.” Walking out of a Yale lecture hall all those years ago after going to see some hot-shit celebrity philosopher so evidently full of himself it practically wafted over the audience, Tony and a friend found themselves walking beside a couple of young women, one of whom said, “That guy was so head-in-ass, it was like listening to a human Möbius strip.” She was short and wide-hipped with an ample rear end and round melon breasts. Her face had the kind of delicate white skin that turns extremely pink from the cold, which it was that night in New Haven. She had a mess of dark blonde hair showering down in large curls and a little stump of a nose that gave her face a slight chipmunk quality. He thought she was gorgeous that night and would continue to think that past a decade and two children whose faces grew into hers year by year. Khaleesi, at age five, looked even more like Older One, who kept looking more and more like her mother. “Marriage,” Gail declared right after Khaleesi was born, and they still couldn’t have sex but she was doing him occasional favors in the bedroom. “Being sick and tired of having the same man’s come in your mouth.”

This was the kind of woman you needed when the world was teaming with morons, and you got hate mail for studying the phase transitions of methane hydrates.

His eyes crept back to the beginning of the letter. “After this,” it began. After what? Obviously it implied a forthcoming action. That

was the nature of the threat. Tony wondered if he should call campus security to get an escort to his car for a few days. This seemed silly, though. He wasn't particularly worried about a guy being camped out in the bushes waiting for him. Some idiot had scanned the Scripps faculty page on the website and picked his name out of a hat. He set the letter down on his desk, ready to forget about it for the rest of the day, when he noticed something white with a pale yellowish tint on his right hand. He rubbed the tips of his fingers together and the substance sifted off. Still holding the envelope with his left, he now felt a remaining weight to it. There was something else inside.

Without thinking, he tilted the envelope over the desk to empty the rest of the contents. A powder of the same color, maybe a couple spoonfuls, spilled out onto the marred wooden surface.

It was impossible for Tony to remember how long he sat there staring at it, but it was a very long time. His mind, chaotic and symphonic only moments before, halted entirely. He swam through molasses to arrive at each new conclusion, and these conclusions were like buoys in this viscous sea. It so exhausted him to do the swimming that he clung to each buoy and did not feel safe leaving it.

This obviously wasn't real. It was likely chalk or some other completely anodyne substance. This was some idiot's notion of a joke or some sick crank's idea of a scare tactic.

He tried to think of everything he knew about *Bacillus anthracis*, but it wasn't much. Cutaneous, pulmonary, or gastrointestinal methods of infection were all possible—but here he was just breathing, just sitting there, staring at his hands and breathing, some of it still on his fingers from the letter. But as his mind sped up, he questioned what were the odds that a clueless loser who couldn't spell "youll" properly somehow had access or the wherewithal to cultivate *Bacillus* spores? Likely low to nil. Then again, the historic mortality rate had to be incredibly high. Other than recreational reading on a few of the more relevant biological sciences, his entire body of knowledge revolved around physical sciences—the ones that dominated and dictated to the biological, that permitted all the haughty, glorified celled and multi-celled organisms on Darwin's march to feel important for a blink on the geological timescale.

He became aware of a piece of food stuck in his teeth, leftover from lunch, and realized he was still just staring at the powder on his hands.

As if borne back into his surroundings at that moment, he looked up and around. He shared the lab in Nierenberg Hall on the east side of the Scripps campus with Niko, but since they only dealt in computer

models they treated it as an overflow office. The cabinets that had once held equipment now stored files and reams of other hard copy detritus. The countertops that might have held aquariums of marine specimens now provided a home to his and Niko's research flotsam. Mountains of paper, like typewriters were still the highest technological form. But there was still a working sink.

Tony stood, wondering if he could inadvertently wash the spores into someone's drinking water. Because he had no answer to this question, he dismissed it and knocked the faucet on with his elbow. The powder vanished as soon as the water, warm then scalding, flowed over his skin. He emptied a handful of the pink gel from the soap dispenser onto his hands and scrubbed for a long time. He wanted it to be longer than he'd sat staring at the goddamn stuff without moving.

When he finished, he dried his hands on his pants and dialed 911 from his cell phone. He'd barely explained the situation before the operator was putting him in touch with the FBI.

By the time he hung up, he was confused. The FBI was coming, but what about an ambulance? He remembered from the scares of 2001 that *Bacillus* wasn't contagious from person to person, so could he just drive to the hospital himself? He didn't want to sit at his desk where the pile of powder had accumulated in the shape of a runty California mountain, so he took Niko's desk chair and sat by the opposite wall near a stack of boxes, as far away from his desk as he could, and wondered if he should lay a piece of plastic over the powder. Then again, he didn't want to get near it. He sat hunched forward with his arms crossed over his chest, hugging himself. Even though it was surely a hoax, almost definitely a hoax, maybe it wasn't a hoax. And the less he tried to think about this, the more he could only think about it. He felt a tickle in his throat and cleared it. He wondered if in a few minutes or an hour he'd start coughing. Wishing for the anti-anxiety meds he'd briefly dabbled with as an undergrad, he tried to focus his mind on something else, and he wanted this to be his family. Gail, Holly, and Catherine. His mom and dad.

But that wasn't where his mind went. Instead, he was overcome by an image of tiny bubbles rising inexorably through dark water. It was what he'd seen in the data just before he pulled the letter from the envelope. Not a revelation—there were no revelations in the granular world of research—but with this data set, the trend was becoming unmistakable. And powerful. He and Niko kept fiddling with the parameters for the simulation, but in the end, it took such a little shove. They made the parameters looser, the stresses milder, but the hypothetical hydrates kept coming apart. He tried to focus on other things: Gail working on

her dissertation in the kitchen of their first rental home in La Jolla while he kept Holly—not yet Older One—distracted in the living room by handing her little baby toys to suck on while he read research papers a paragraph at a time. Gail had Holly by day, so he took her by night, and they both pursued their careers while they fed and burped this chubby blonde babbling machine, and when she finally began going down at a reasonable hour, they'd watch DVRed episodes of *Lost*, which Gail claimed offended her as a reader of literature, even though she never let him watch without her.

When Catherine came they talked about how their girls would be the two most dissimilar sisters, as fundamentally different siblings as Gail and Cory. Older One got the hang of reading by age six, and she seemed in a competition with herself to comprehend the most challenging novel her young mind could follow. When she was only a first grader, they had to take the James Howe series about the vampire bunny away from her when she went to bed or when the stifled giggles would drift through the vents, and they'd find her holed up under the covers with a flashlight. The *Harry Potter* series fell seemingly overnight. Now she was on to Richard Adam's *Watership Down* as an eight-year-old, and God knew what after that. She kept so quiet, she objected to so little, she threw no tantrums, and yet she almost seemed to carry around a latent fear or stress that she would never manage to finish every great book in the world. And the ways in which she put that unrelenting curiosity to work never failed to astonish Tony, like when Gail taught her what it meant to call something "gender essentialist," and she began correcting basically everything in the modern world as "gendered essentialist," including TV commercials, children's shows, movies, all sports, and everything her Uncle Cory ever said.

And her younger sister—Jesus Christ. Even as an infant incapable of much rational thought, she had a knack for the bold entrance and destructive tantrum. She could charm an entire room or, if she didn't like the vibe, as Gail put, "She'd spit at us if she could get her lips to work." Then she learned to talk, and in complete contrast to Older One, the words never stopped. They just came in an endless stream of thoughts, ideas, stories, questions, and wonders. He learned to tune much of it out. "Right, Diddy? Right, Diddy," was her frequent incantation to him, the latter word always pronounced like the eponymous rap mogul. A slow, humble, "Yes, Khaleesi," would suffice most of the time, especially when he learned how to trick her into thinking it was her idea to go to bed. And her crazy streak: when Niko, his wife, Bethany, and some other friends had come over for dinner once, he and Gail

had returned from the kitchen to find their youngest daughter bare-ass naked demonstrating her toddler gymnastics for the assembled guests, who were encouraging her to put her underwear back on. Tony had stepped back into the living room just in time to see his child stretch both her legs behind her head and roll onto her back, tongue lolling out of her mouth with focus, unaware that this unintentional display of her tiny pink vagina to their guests was going to cause the rarest of lost tempers from her parents. But then that was why she was a conqueror, a wild one, fearless and fierce, the Mother of Dragons.

He shut his eyes and tried to grip these memories, but each one became subsumed by the image and the weight of a dark ocean boiling.

Eventually, there was a knock on the lab door.

He dealt with an FBI agent named McDonald, who could not have been more out of central casting. Neat, combed hair, workaday suit over a muscular build, pen, pad, and latex gloves. He was so no-nonsense that after the biohazard unit had put police tape over the door and collected the powder, Tony felt a simmering panic at the man's calm.

"Should I go to the hospital?" he asked.

The agent's eyes flitted up and back down to a notepad where his hand moved furiously.

"Do you feel any of the symptoms we talked about?"

"No. I mean, my throat tickles a little, but it kind of did this morning."

"Anthrax poisoning tends to produce a little more than a throat tickle. You said you have a change of clothes—put those on, give us yours. Go home, shower, and if you start to feel real symptoms, go to the hospital. I'll call you tomorrow as soon as the lab looks at this."

The farther away Tony got from the office and the envelope, the less plausible the threat felt. By the time he got home and told Gail, he was behaving as though it was nothing more than the stupidest of pranks, what with the entire floor having to avoid their offices while the FBI unit did its work.

Gail spent a minute staring at him in uncomprehending horror, a minute hurling profanities at him for not going to the hospital immediately, and then several more reading the anthrax Wikipedia page.

"So we're assuming you haven't been poisoned? That's the assumption we're all operating under?" Her chocolate eyes glared at him.

"The FBI seemed to think it wasn't worth worrying about unless I felt ill."

Gail blew an imaginary strand of hair out of her face, a very Gail tell for a snarky comment forthcoming. "I really hope whoever this guy is,

he understands the awesome dramatic irony of being scientifically literate enough to use science to make an anti-scientific terrorist attack.”

“They really didn’t seem to think it was necessary, I swear to you. If they thought there was a reason to worry I’d be there right now.”

“Fine,” she said, embracing him and tucking her head underneath his chin so that her ear aligned with his heart. “But I swear, Tone, if you die I’m blowing every mailman who comes to the door.”

The next day Agent McDonald called Tony to tell him that he was in the clear. The powder had been cornmeal.

“Cornmeal,” Tony repeated. “To what goddamn end?”

“No cheaper way to put a scare into someone. It’s why we tend not to break out Seal Team Six every time someone gets the idea.” McDonald had a conversational presence like he was reading out of a phone book. “We’re still going to try to trace this letter. A powder threat—even if it’s a hoax—is still a felony.”

But they never found the guy who mailed cornmeal and the letter with its big block font. Tony never received another such threat, though when he and Niko secured a grant to finish their work and published their findings a year later, the e-mails did start to trickle in. These were less death threats and more hateful accusations and childish name-calling. They both quickly learned to ignore them. Gail took to calling Tony “Anthrax” every now and again, but she mostly employed the nickname after the speaking offers began to roll in. This wasn’t so much to recall the cornmeal death threat as to recall that period of their lives, that whatever kind of scientific superstar he became, he was still yet the crabby old nerd. The story of the letter became a party anecdote. Gail prodded him to tell it at social gatherings when the conversation dragged.

“I like the way it makes you sound,” she once explained when he asked why she made him tell it. “Brave. Resilient. Fearless.” She cupped his aging butt and winked.

“Why?” he said, smiling. “All I did was shit my pants and call the FBI.”

The story disappeared into the archive of memories that lose all urgency. Except that wasn’t quite right. What he never could have predicted was the part of that experience that did stick with him. That of the image that overwhelmed him as he sat in Niko’s chair waiting for the cavalry. It washed him away for a moment. The walls of the office had not closed in like a tomb but rather expanded and deepened to almost infinite space and depth. Down there in the vivid blue darkness, in the cold, crushing rapture of the pressure, there was imperceptible warmth.

The mounds of dirty yellow ice—the color of dog urine on snow—were leaking. Other clumps of the whitest frozen lattice-work, opaque crystals, fizzed like an Alka-Seltzer. Or belching up from minor cracks in the rock, these little farts in the dark, that sent schools of pebble-sized bubbles ascending. Or gurgling from invisible pores in the sand and sediment of the ocean floor, beading up, clinging momentarily, and then writhing free of a soft sand carpet. Zipping back and forth, they climbed through the frigid water, darting erratically in crazed zigzagging steps. A mad poetry scrawled in the unseen corners of the water.

In the years that would follow, this image—but not just an image, a sensation so real and so deep that it had the power to blot out his vision—would settle upon him in moments of his most pressing fear. When Gail came home and told him her doctor had found a metastatic lump in her breast at her improbably young age. When they'd found out that it had already spread to her bones, that this wasn't the kind of breast cancer where you got to traipse around with a pink ribbon for a few years. This was the kind that took you. And when it took her, so rapidly and so without mercy or time to come to grips or even fucking think, and he'd sat in the kitchen not knowing how to explain it to the girls, he felt it. He felt it when he told Older One that he'd probably need help cooking dinner for a while, and she'd whispered that this was kind of gender essentialist without understanding how violently this would crack open his heart. And he felt it then again, years later, when a teenage Khaleesi got into a car accident, and the idiot father of the idiot boy she'd been with couldn't remember the name of the hospital they'd been taken to, and Tony spent ten panicked minutes dialing hospitals around La Jolla and San Diego before the asshole called back with the information. He felt it when he saw the Mother of Dragons in a hospital bed with her arm in a sling, dried blood in her hair, and a nasty couple of black eyes that would set back her accelerating beauty for a few months. He felt it when he went to her, and she said his name the way she had as a child.

He'd feel that same eclipsing terror, born on the day of the letter, in the same familiar way, and all he could see were the bubbles, and then beyond that into the very molecule itself. That invaluable atomic combination in its prison of ice, struggling its eternal life away in a tomb until it broke free and began its dauntless journey through the depths and on to the invisible wastes at the crown of the world.