BILL STREEVER

COLD

ADVENTURES IN THE WORLD'S FROZEN PLACES

"The meaning of this unexpectedly beautiful and ever-intriguing book gathers and deepens like fresh falling snow: cold, Bill Streever shows us, shapes life as we know it, and we'll sorely miss it if it goes."

—ALAN WEISMAN, AUTHOR OF *THE WORLD WITHOUT US*

Copyright

Little, Brown and Company
Hachette Book Group
237 Park Avenue, New York, NY 10017
Visit our website at www.HachetteBookGroup.com
www.twitter.com/littlebrown

First eBook Edition: July 2009

Little, Brown and Company is a division of Hachette Book Group, Inc.
The Little, Brown name and logo are trademarks of Hachette Book Group, Inc.

ISBN: 978-0-316-05246-7

Contents

For my son, Ishmael, who never thinks
it is too cold to play outside

I think myself obliged to give my Readers an account….
Why I thought fit to write of Cold at All?… The subject I have chosen is very noble.

— Robert Boyle, *New Experiments and Observations Touching Cold*, 1683

The captain had been telling how, in one of his Arctic voyages, it was so cold that the mate's shadow froze fast to the deck and had to be ripped loose by main strength. And even then he got only about two-thirds of it back.

— Mark Twain,
Following the Equator, 1897

AUTHOR'S NOTE

Throughout this book, degrees Fahrenheit are used unless noted otherwise because this is the temperature scale most familiar to readers in the United States. Forty below zero Fahrenheit is equal to forty below zero Celsius, and thirty-two degrees Fahrenheit is equal to zero Celsius.

PREFACE

The world warms, awash in greenhouse gases, but forty below remains forty below. Thirty degrees with sleet blowing sideways is still thirty degrees with sleet blowing sideways. Cold is a part of day-to-day life, but we often isolate ourselves from it, hiding in overheated houses and retreating to overheated climates, all without understanding what we so eagerly avoid.

We fail to see cold for what it is: the absence of heat, the slowing of molecular motion, a sensation, a perception, a driving force. Cold freezes the nostrils and assaults the lungs. Its presence shapes landscapes. It sculpts forests and herds animals along migration routes or forces them to dig i for the winter or evolve fur and heat-conserving networks of veins. It changes soils. It preserves food It carries with it a history of polar exploration, but also a history of farming and fishing and the invention of the bicycle and the creation of Mary Shelley's *Frankenstein*. It preserves the faithful in vats of liquid nitrogen from which they hope one day to be resurrected.

Imagine July water temperatures of thirty-five degrees. Imagine Frederic Tudor of Boston shipping ice from Walden Pond to India on sailing ships in 1833. Imagine Apsley Cherry-Garrard on his search for penguin eggs at seventy below zero in 1911. Imagine a dahurian larch forest that looks like a stand of Christmas trees on Russia's Taymyr Peninsula at sixty below or a ground squirrel hibernating until its blood starts to freeze and then shivering itself back to life.

But none of this is imaginary. Our world warms, but cold remains. In the ordinary passing of a calendar year, the world of cold emerges. For someone with Raynaud's disease, a September stroll temporarily changes cold hands into useless claws. Caterpillars freeze solid in October and crawl away in April. Average temperatures in certain towns drop to twenty below zero in January.

It is time to enjoy an occasional shiver as we worry about a newly emerging climate likely to mel our ice caps, devour our glaciers, and force us into air-conditioned rooms. It is time to embrace and understand the natural and human history of cold. Even in a warming world, a world choked by carbo dioxide and methane, cold persists, biting my lungs and at the same time leaving me invigorated, aliv and well on an Arctic spring afternoon with the sun hovering low over an ice-covered horizon and the thermometer at forty below.

JULY

It is July first and fifty-one degrees above zero. I stand poised on a gravel beach at the western edge of Prudhoe Bay, three hundred miles north of the Arctic Circle, and a mile of silt-laden water separates me from what is left of the ice. The Inupiat — the Eskimos — call it *aunniq*, rotten ice, sea ice broken into unconsolidated chunks of varying heights and widths, like a poorly made frozen jigsa puzzle. A few days ago, the entire bay stood frozen. During winter, it is locked under six feet of ice. Trucks drive on it to resupply an offshore oil production facility. If one were insane, or if one were simply too cheap to fly, or if boredom instilled a spirit of adventure, one could walk north to the Nor Pole and then south to Norway or Finland or Russia. Temperatures would range below minus fifty degrees, not counting windchill.

But even in summer, the weather resides well south of balmy. A chill gust runs through me as I stand shirtless on the water's edge, wearing nothing but swimming shorts in the wind and rain.

"The only way to do this," I tell my companion, "is with a single plunge. No hesitation."

I go in headfirst. The water temperature is thirty-five degrees. I come up gasping. I stand on a sandy bottom, immersed to my neck. The water stings, as if I am rolling naked through a field of nettles. I wait for the gasp reflex to subside. My skin tightens around my body. My brain — part of it that I cannot control — has sent word to the capillaries in my extremities. "Clamp down," my brain has commanded, "and conserve heat." I feel as if I am being shrink-wrapped, like a slab of salmon ju before it is tossed into the Deepfreeze.

My companion, standing on the beach, tells me that I have been in the water for one minute. My toes are now numb.

Time passes slowly in water of this temperature. I think of the ground, permanently frozen in this region to a depth of eighteen hundred feet. I think about hypothermia, about death and near death fro cold. I think of overwintering animals. I think of frozen machinery with oil as thick as tar and steel turned brittle by cold. I think of the magic of absolute zero, when molecular motion stops.

After two minutes, I can talk in a more or less normal tone. But there is little to discuss. There is, just now, almost no common ground between me and my companion, standing on the beach. I feel more akin to the German soldiers whose troop carrier foundered, dumping them into Norwegian coastal waters in 1940. Seventy-nine men did what they could to stay afloat in thirty-five-degree water. All were pulled alive from the water, but the ones who stripped off their clothes to swim perished on the rescue boat. Suffering more from hypothermia than those who had the sense to stay clothed, they succumbed to what has been called "afterdrop" and "rewarming shock." Out of the water, they reportedly felt well and were quite able to discuss their experience. But as the cold blood from their extremities found its way to their hearts, one after another they stopped talking, relaxed in

their bunks, and died.

"Three minutes," my companion tells me.

I am a victim of physics. My body temperature is moving toward a state of equilibrium with this water, yielding to the second law of thermodynamics. I shiver.

Several hundred miles southwest of here, six days before Christmas in 1741, the Dutch navigator Vitus Bering, employed by Russia, lay down in the sand and died of scurvy and exposure, while his men, also immobilized by scurvy, cold, and fear, became food for arctic foxes. Some accounts hold that Bering spent his last moments listening to the screams and moans of his dying men. The Bering Sea, separating Russia and Alaska, was named for him, and the island where he died, nestled on the international date line, is known today as Bering Island.

Northeast of here, in 1883, Adolphus Greely led twenty-five men to the Arctic, stopping at Ellesmere Island. For most of them, the trip was a slow death that combined starvation, frostbite, and hypothermia. Greely himself, with five others, survived. He eventually took charge of what would become the National Weather Service, where he failed to predict a blizzard in which several hundred people died from frostbite and hypothermia. Many of the dead were schoolchildren.

Half a century after Greely's expedition, in the 1930s, the missionary ascetic Father Henry lived a Pelly Bay, in Canada's Northwest Territories, well above the Arctic Circle. By choice, he resided in a ice cellar. Indoor temperatures were well below zero. The natives would not live in an ice cellar, which was designed to keep game frozen through the short Arctic summer. It was the antithesis of a shelter, analogous to living in a shower stall to avoid the rain. Father Henry believed that it focused his mind on higher matters. Almost certainly, some of the natives believed that Father Henry was mad.

"Four minutes," my companion calls. The stinging in the skin of my thighs has turned to a burnin pain. Frostbite is not a real possibility at this temperature, and true hypothermia is at least ten minute in the future. What I feel is no more than the discomfort of cold.

Frogs are not found this far north, but at their northernmost limit, five hundred miles from here, they overwinter in a frozen state, amphibian Popsicles in the mud. Frogsicles. But caterpillars are found near here. I sometimes see them crawling across the tundra, feeding on low-growing plants. They freeze solid in winter, then thaw out in spring to resume foraging between clumps of snow. The are especially fond of the diminutive willows that grow in the Arctic.

Ground squirrels overwinter underground. They are related to gray and red squirrels and to chipmunks, but in appearance they are more similar to prairie dogs. In their winter tunnels, their bod temperature drops to the freezing point, but they periodically break free from the torpor of hibernation, shivering for the better part of a day to warm themselves. And then they drift off again into the cold grasp of hibernation. Through winter, they cycle back and forth — chill and shiver, chil and shiver, chill and shiver — surviving.

Arctic soil behaves strangely around the hibernating ground squirrels. Underground, liquid water is sucked toward frozen water, forming lenses of almost pure ice. The soil expands and contracts wit changing temperatures, forming geometric shapes, spitting out stones on the surface, cracking building foundations. Wooden piles cut off at ground level are heaved upward by ground ice, sadly mimicking a forest in this frozen treeless plain.

This water I stand in feels frigid, bitingly cold, but in the greater scheme of things it is not so col A block of dry ice — frozen carbon dioxide — has a surface temperature just warmer than minus 110 degrees. James Bedford has been stored in liquid nitrogen at minus 346 degrees since 1967, awaiting cure for cancer. The surface of Pluto stands brisk at minus 369 degrees. Absolute zero is some five

hundred degrees colder than the water that surrounds me.

"Five minutes," my companion tells me. I leave the water, shivering, my muscles tense. It will be two hours before I feel warm again.

❄ ❄ ❄

There is more than one way to measure temperature. Daniel Fahrenheit, a German working in Amsterdam as a glassblower in the early 1700s, developed the mercury thermometer and the temperature scale still familiar to Americans. He built on work dating back to just after the time of Christ and modified by the likes of Galileo, who used wine instead of mercury, and Robert Hooke, appointed curator of the Royal Society in 1661, who developed a standard scale that was used for almost a century. In 1724, Fahrenheit described the calibration of his thermometer, with zero set at th coldest temperature he could achieve in his shop with a mixture of ice, salt, and water, and 96 set by sticking the instrument in his mouth to, in his words, "acquire the heat of a healthy man." He found that water boiled at 212 degrees. With only a minor adjustment to his scale, he declared that water froze at 32 degrees, leaving 180 degrees in between, a half circle, reasonable at a time when nature was believed by some to possess aesthetic symmetry.

Anders Celsius, working in Sweden, came up with the Celsius scale in 1742. Conveniently, it put freezing water at zero and boiling water at one hundred degrees. Less conveniently, it set in place a competition between two scales. An Australian talking to an American has to convert from Celsius to Fahrenheit, or the American will think of Australia as too cold for kangaroos. An American talking to an Australian has to convert from Fahrenheit to Celsius, or the Australian will think of America as too hot for anything but drinking beer. The Australian is forced to multiply by two and add thirty-two, or the American is forced to subtract thirty-two and divide by two. Or, as more often happens, they drop the matter of temperature altogether.

Lord Kelvin realized in 1848 that both Fahrenheit and Celsius had set their zero points way too high. He understood that heat could be entirely absent. At least conceptually, absolute zero was a possibility. He came up with his own scale, based on degrees Celsius, but with zero set at the lowest possible temperature, the point at which there is no heat. Zero Kelvin is 459 degrees below zero Fahrenheit. Just above this temperature, helium becomes a liquid. Anywhere close to absolute zero, and all things familiar to the normal world disappear. Molecular motion slows and then stops. A new state of matter, called a "super atom" — something that is neither gas nor liquid nor solid — comes into being. But Kelvin's understanding of the strange world that exists within a few degrees of absolute zero was theoretical. By the time he died, in 1907, his colleagues were struggling to force temperatures colder than 418 degrees below zero, 41 degrees above absolute zero, and helium had not yet been liquefied.

One of the physicists who first achieved a temperature low enough for the formation of a super atom, which did not occur until 1995, had this to say: "This state could never have existed naturally anywhere in the universe, unless it is in a lab in some other solar system."

Our planet's polar explorers used, for the most part, Fahrenheit's scale, but rather than talking of degrees below zero, they often talked of "degrees of frost." One degree of frost was one degree below freezing Fahrenheit. An explorer might write in his journal of fifty degrees of frost — eighteen degrees below zero Fahrenheit — and in the next paragraph tell of the amputation of a frozen toe, or describe himself gnawing on a boot to stave off the starvation that so often accompanies cold, or mention in passing how he had to beat fifteen pounds of ice from the bottom of his sleeping bag

before bedding down for the night. Or, after an especially cold and uncomfortable spell, he might write of the relative warmth and relief of fifty-five degrees below zero Fahrenheit. Apsley Cherry-Garrard, who supported Robert Falcon Scott on his disastrous 1910 Antarctic expedition, did just that. "Now," he wrote, "if we tell people that to get only 87 degrees of frost can be an enormous relief they simply won't believe us." But an enormous relief it would be for one accustomed to camping at 75 degrees below zero, or 107 degrees of frost.

In his memoirs, Cherry-Garrard concurred with Dante, who placed the circles of ice beneath the circles of fire in his vision of Hell.

❄ ❄ ❄

It is July eighteenth and nearly fifty degrees under an overcast sky. I walk slowly across Arctic tundra next to an abandoned airstrip, stalking *Gynaephora rossii*. The trouble with this beast — the woolly bear caterpillar of the far north — is that it is not easy to find here near Prudhoe Bay. Woolly bear caterpillars are substantially smaller than woolly mammoths. Woolly mammoths, but for their unfortunate extinction, would be easy to spot. But these woolly bear caterpillars are smaller than a mammoth's eyebrow. And this terrain is not conducive to stalking insect larvae. Though flat and treeless, the terrain is uneven. The prudent searcher watches his footing when he should be watching for caterpillars. Every few steps, water-filled cracks in the ground require minor detours. The cracks form when the ground contracts and expands in response to temperature changes. Once a crack forms it fills with water. When the water freezes, the ice expands and widens the crack. A wedge of ice forms and grows, and the crack eventually becomes too wide to step across. Cracks intercept other cracks. Together, they make a network outlining polygons that are thirty feet wide. They polygonize the landscape.

The cracks are beginning to find their way across the abandoned airstrip. Next to the cracks, where water pools through the summer months, grass grows lusciously green. Between the cracks, in the centers of the polygons, the greenery struggles — less dense, less luscious. Or even not luscious at all. Despite all this water, the ground can be dry between the cracks, and dust covers some of the plants. Just days ago, the creamy flowers of arctic dryas made patches of this dry ground look like miniature gardens of snowy roses. Now their dried scraggly puffball seed heads are all that remains. In the Arctic, blink, and summer is gone.

Underneath, eighteen inches down, the ground is frozen. It remains frozen for a third of a mile before heat from the earth's innards overcomes the cold from above. Poking the ground with a steel rod, one can feel the permafrost — the permanently frozen ground. It's like hitting bedrock just eighteen inches down.

Where are the caterpillars? I find a biologist who has been working here since May, counting birds. I ask her if she has seen any caterpillars. "I've only seen one," she tells me.

Later, I talk to an Inupiat elder. "I see them sometimes," he says. "Maybe once each year." Inupiat frequently pause when they talk, leaving what might seem like an uncomfortable silence. I have been told that the pauses give them time to think and therefore to avoid the mindless patter of whites. "They like high ground," he says after a moment. "I see them near my camp at Teshekpuk Lake."

The little beasts eat willow buds. I squat on the tundra to check some of the willows growing on the high ground between water-filled cracks. These willows are related to the taller willows of warmer climates, but they never stand more than a few inches tall. Their trunks can be measured in fractions of an inch. I find neither caterpillars nor gnawed buds. I pluck a leaf and pop it into my mouth. It

tastes like an aspirin salad. I move on.

Hyperactive birds fly around the airstrip. A plover screeches at me and makes threatening dives, driving me away from its young. In tundra ponds and in water-filled cracks, phalaropes swim in tight circles, their heads bobbing as if connected to their feet. A pair of snow buntings perch for a second o top of a pipeline next to the airstrip and then fly off. A long-billed dowitcher, its beak disproportionately long, flushes from the ground in front of me. Behind it, a hundred yards away, five caribou graze, their antlers imitating the beak of the dowager in their freakish length.

Soon all of this activity will cease. The birds will fly away. The caribou will march south. The caterpillars will simply freeze. That is why I am interested. That is why I want one of these caterpillars. The little devils have figured out how to freeze solid without dying. They are slow growers. It might take a decade before they are ready to metamorphose into grayish moths. That means they survive through ten winters here in the Arctic. When spring comes, they thaw and go back to eating. For a pet lover who travels, they could be the perfect solution. Cute, furry, and quiet, and th freezer serves as a kennel. But where are they? If I were looking for oil, I would have just successfull drilled a dry hole, a duster. I have been skunked by a caterpillar.

❄ ❄ ❄

The polar explorers were great keepers of journals, and many of the survivors produced memoirs. Cold for the polar explorers came with a sense of pride, but also uncertainty, hunger, exhaustion, and death. The body's boilers run on food, and as often as not, death from prolonged exposure to cold combines starvation, frostbite, and hypothermia. When one reads past the stoicism and heroics, the history of polar exploration becomes one long accident report mixed with one long obituary.

There was, of course, discomfort. In 1909, Ernest Shackleton traveled to within ninety-seven mile of the South Pole. Realizing that his provisions would be stretched if he pushed farther, he turned around. He told his wife, "I thought you would rather have a live donkey than a dead lion." In 1914, during a later exploration, his ship *Endurance* was iced in and eventually abandoned. He led his men slowly across the ice. In his travelogue, he wrote, "I have stopped issuing sugar now, and our meals consist of seal-meat and blubber only, with 7 ozs. of dried milk per day for the party." This is at a tim of inactivity, camped on ice. "The diet suits us, since we cannot get much exercise on the floe and the blubber supplies heat," he wrote. Eventually, the ice gave way, cracking under his camp. "The crack had cut through the site of my tent," he wrote. "I stood on the edge of the new fracture, and, looking across the widening channel of water, could see the spot where for many months my head and shoulders had rested when I was in my sleeping bag."

Charles Wright survived Robert Falcon Scott's 1910 Antarctic expedition and knew just how important those sleeping bags were. He — with Apsley Cherry-Garrard, who had grasped Dante's reasons for placing the circles of ice beneath those of fire in the depths of Hell — was one of the men who supported Scott, hauling Scott's gear south for the first leg into the heart of Antarctica. The support team turned back and waited at their base camp, but Scott and the four men who continued to the pole would not survive. Long afterward, at eighty-six years old, Wright talked to an interviewer about man-hauling sleds in Antarctica. The interviewer asked about toilet habits on the trail, the point being that getting up in the middle of the night to relieve oneself involved more than just stepping outside of the tent in your boxers. "You see," Wright explained,

> you've come from your sleeping bag, you've taken into the sleeping bag all the frozen sweat

of the previous day, and the previous day and the previous day and the previous day. There's a log of it at the end. And during the night you first melt that frozen sweat. And very often it freezes at the bottom of the bag, where your feet are. And if you're going to have a decent night you've got to melt all that before you have a chance. And even then it's not comfortable because whatever is next door is wet and cold, and every breath you take brings some of the cold stuff into the small of your back. So a winter's night when you're sledging is not a comfortable thing at all. But you've got to, before you get anywhere, you've got to melt the ice. And sometimes there's fifteen pounds of ice or something like that that's got to be turned into water before you begin to sleep.

From Wright's account it is clear that Antarctic explorers disciplined their bladders and stayed in those half-frozen bags as long as possible.

Scott himself kept a journal right up until his death. Eight months later, a search party found his camp. In the camp, Scott's frozen body lay between two of his frozen companions. The three men in the tent, it has been said, looked as if they were sleeping. The three bodies, along with Scott's journal were recovered.

Scott's journal records noble behavior and tragedy. By the middle of January 1912, eager to be th first to reach the South Pole, Scott and the four men who went with him stumbled on sled tracks and camps left by the Norwegian explorer Roald Amundsen, who had beaten them to the pole by four weeks. Scott's party pressed on to the pole anyway. "Great God!" Scott wrote, "this is an awful place and terrible enough for us to have laboured to it without the reward of priority." Disappointed, the men struggled back toward their base camp.

"Things steadily downhill," Scott wrote in early March. "Oates' foot worse. He has rare pluck and must know that he can never get through. He asked Wilson if he had a chance this morning, and of course Bill had to say he didn't know. In point of fact he has none." Later, Oates, recognizing that he was slowing the party and endangering their lives, talked to his companions. "I am just going outside and may be some time," he said. Afterward Scott wrote, "He went out into the blizzard and we have not seen him since."

Scott wrote about himself, "My right foot has gone, nearly all the toes — two days ago I was prou possessor of best feet. These are the steps of my downfall. Like an ass I mixed a small spoonful of curry powder with my melted pemmican — it gave me violent indigestion. I lay awake and in pain al night; woke and felt done on the march; foot went and I didn't know it. A very small measure of neglect and have a foot which is not pleasant to contemplate. Amputation is the least I can hope for now, but will the trouble spread?"

Later he wrote, "It seems a pity, but I do not think I can write more." And after this, he had but on final entry: "For God's sake look after our people." Scott ended his days eleven impossible miles fro a supply depot that would have saved his life.

Frostbite is a common theme among polar explorers. Captain George E. Tyson was marooned wit his crew on an Arctic ice floe in the winter of 1872 and spring of 1873. "The other morning," he wrot "Mr. Meyers found that his toes were frozen — no doubt from his exposure on the ice without shelte the day he was separated from us. He is not very strong at the best, and his fall in the water has not improved his condition."

Food, or a lack of food, is another common theme. Roald Amundsen, when he beat Robert Falcon Scott to the South Pole, used sleds pulled by dogs. The dogs doubled as a food supply. Amundsen had this to say about men who pursued their destinies at the poles: "Often his search is a race with time

against starvation."

Robert Flaherty published the story of Comock, an Inuit. In the narrative, Comock explains how h and his family lived on Mansel Island in the Canadian Arctic early in the twentieth century. They we on the island alone, isolated for ten years from their extended families and the villages that dotted th Arctic. They were at times well fed.

"Look at our children," Comock's wife said to Comock. "They are warm."

And Comock, in his narrative, added, "There were little smokes rising from the deerskin robes under which they slept."

But later, food became scarce. "We shared with our dogs the dog meat upon which we lived," Comock reported. One of his companions said that seal meat offered warmth, while dog meat did not Comock feared the dogs would eat the children.

Frederick Cook, who probably reached or at least came close to the North Pole in April 1908, almost a full year before Robert E. Peary, ran into trouble and could not return to civilization quickly enough to defend himself against Peary's own claim and what has been described as Peary's slander. Like Apsley Cherry-Garrard, Cook concurred with Dante, but with more drama and self-aggrandizement: "We all were lifted to the paradise of winners as we stepped over the snows of a destiny for which we had risked life and willingly suffered the tortures of an ice hell." But after two days at the pole, he described a feeling of anticlimax. The pole itself, after all, was just another froze camp in a frozen landscape. "The intoxication of success was gone," he wrote in his memoir. "Hungr mentally and physically exhausted, a sense of the utter uselessness of this thing, of the empty reward of my endurance, followed my exhilaration."

And who has heard of Lieutenant George De Long? In an 1879 attempt to reach the North Pole, D Long and twenty men abandoned their ship to the ice. They dragged three small boats across the ice for nearly three months before finding open water. One boat was lost, but two made it to Siberia's Lena River delta. This was early October. Though suffering from frostbite and exhaustion, the men were not complainers. De Long wrote, "The doctor resumed the cutting away of poor Ericksen's toes this morning. No doubt it will have to continue until half his feet are gone, unless death ensues, or we get to some settlement. Only one toe left now. Temperature 18º."

Like Scott, though perhaps with less panache, De Long maintained his journal until the end:

> October 17th, Monday. — One hundred and twenty-seventh day. Alexey dying. Doctor baptized him. Read prayers for the sick. Mr. Collins' birthday — forty years old. About sunset Alexey died. Exhaustion from starvation.
>
> October 21st, Friday. — One hundred and thirty-first day. Kaack was found dead about midnight between the doctor and myself. Lee died about noon. Read prayers for the sick when we found he was going.
>
> October 24th, Monday. — One hundred and thirty-fourth day. A hard night.

The next two days contain only the date and the number of days. Then:

> October 27th, Thursday. — One hundred and thirty-seventh day. Iversen broken down.
> October 28th, Friday. — One hundred and thirty-eighth day. Iversen died during early evening.
> October 29th, Saturday. — One hundred and thirty-ninth day. Dressler died during night.
> October 30th, Sunday. — One hundred and fortieth day. Boyd and Gortz died during night. Mr. Collins dying.

The bodies of De Long and nine others were recovered the following spring.

❄ ❄ ❄

It is July twenty-sixth and sunny. The mercury rises to fifty-two degrees here on Narwhal Island, ten miles north of Alaska's North Slope. Nothing but water and ice separates me from the North Pole. I

have, for the past hour, been taking my jacket off and putting it back on. Each time I take it off, a breeze comes in from the north, from the pack ice, like the draft from an open freezer door. Each tim I don my jacket, the door closes and the breeze stops. I watch the ice flow past, a regatta of white and blue abstract sculptures. One could not quite step from one chunk of ice to the next without swimming, but boating just now would be a challenge. Here is an ice chunk the size of a suitcase, there one the size of a small house, several in a row the size of compact cars. The breeze comes from the north, but the ice moves to the west, propelled by currents, the bulk of each chunk hanging underwater like an aquatic sail.

Occasionally, a chunk of ice strands next to the shore, hard aground. Another chunk butts up against the first. They grind. Water drips from their tops continuously. Pieces of ice break off, dropping into the Beaufort Sea with splashes that sound remarkably similar to those produced by bas jumping in a still pond. I wade into the sea, break off a piece of ice, and pop it into my mouth. It taste as fresh as springwater. The molecules in ice are packed in an orderly fashion, forming crystals. Ther is little space between the molecules for salt ions.

Farther out, between here and the horizon, the ice is more densely packed and in places continuous. Fog banks hover over the ice like plumes of smoke. Occasionally, maybe once each half hour, the pack ice cracks under the pressure of movement, of collisions, of one body striking another The cracking sounds like distant cannon fire.

The beach I stand on is a mix of gravel and sand. It looks as though someone has worked it over with a bulldozer. The ice, in places, has plowed the sand into piles, left deep gouge marks on the shore, or dumped moraines of gravel above the tide line. Although I am on the island's northern shor I can turn and see across the island to the other side, and beyond that the mainland, peppered with oil field facilities. A collapsed wooden shack stands on the island, the remains of a long-forgotten scientific party. A large red buoy stranded near the middle of the island speaks of storm tides or ice overrunning the land. Wandering the island, I see only two species of plants clinging to life in scattered patches. Driftwood has accumulated in bigger patches. The rest seems to be bare sand and gravel.

An arctic tern screams at me, then swoops in, obviously protecting a nest. After four or five swoops, it connects with my hat. It leaves me no choice but to find the nest. I look for a small depression in the sand. The closer I get, the more agitated the bird becomes. It dives closer and close screaming "Warmer, warmer, warmer." It backs off a bit, telling me "Colder, colder," and I change direction. I move slowly, taking a careful step, scanning the ground in front of me, then taking anothe careful step. It swoops at me from behind, but I can see its shadow coming. As I get warmer, the tern gets more aggressive. I duck as its shadow closes in. And there is the nest. This late in the year, the tern has but a single egg to protect. Two feet away, a long-dead chick, its body stiff and its eyes glazed, lies on the sand. I back off, ashamed to have disturbed the nesting tern and its lone surviving egg.

Common eiders nest here, too, in bowls scraped from the sand along the edges of driftwood piles. Their nest bowls are much bigger than those of terns, and they are lined with down — eiderdown, as it turns out, plucked from the breasts of females and prized as the best of down, soft and warm and far better than that of domestic ducks. Most of the eider nests are empty, but a few still hold as many as five pale green eggs, somewhat larger than chicken eggs.

For both the eiders and the terns, these may be second or third nest attempts. It seems late in the year to start a family. By September, the eiders will head for open water, where they overwinter, swimming and feeding. The terns, winter averse, will fly twelve thousand miles to Antarctica and the

return next spring. During its life, a tern will travel a distance equivalent to that of a round-trip to the moon.

I migrate back to the island's northern shore, scanning the ice through my binoculars. I hope to se a polar bear or at least a seal, but all I see is ice and water. Despite the island's name, no narwhals frolic here today. Narwhals, with their long tusks, live beneath the ice, coming up to breathe in open leads and holes, and moving toward coastal areas in summer. They are common in the Atlantic secto of the Arctic, well to the east. The rare straggler finds its way to Alaska, but I have not seen one in these waters in the five years I have been coming here. The island, someone tells me later, was name for a nineteenth-century whaling ship rather than the narwhal itself.

The seals, the polar bears, and the narwhals mock me, like woolly bear caterpillars, here yet not here, here yet nowhere to be seen.

❄ ❄ ❄

Adolphus Greely, then a lieutenant in the U.S. Army, led his twenty-five men north in the summer of 1881. They made it past eighty-three degrees, some four hundred miles south of the pole, then turned around. The relief ship intended to pick them up could not pass through the ice. A second relief ship sank. The men froze and starved in the far north.

Before it was over, Greely's men experienced an intense aloneness and ate caterpillars. They also ate leather shoelaces. Sealskin lashings became stew. Sleeping bag covers in the nineteenth century were oiled to render them waterproof, and well boiled, the covers were rendered into broth. The men found crumbs of bread as the snow melted around their camp. They lamented the absence of plants and lichens that in other times would not have been considered fit for consumption. They ate hundred of pounds of amphipods — sea fleas — using, among other things, the remains of dead comrades as bait. One man ate bird droppings, apparently convinced that undigested seeds that passed through birds' guts would provide sustenance. The men divided the soles of an old pair of boots. Later, there would be accusations of cannibalism.

"Everybody was wretched," Greely wrote later, "not only from the lack of food, but from the cold to which we are very sensitive." Like other Arctic explorers, his narrative is one of death: "Lieutenan Kislingbury, who was exceedingly weak in the morning at breakfast, became unconscious at 9 a.m. and died at 3 p.m. The last thing he did was to sing the Doxology and ask for water." The men shared sleeping bags to conserve warmth: "Ralston died about 1 a.m. Israel left the bag before his death, but remained until driven out about 5 a.m., chilled through by contact with the dead." Greely had one ma shot for stealing food.

Sergeant David Brainard kept a journal. Like Greely, he focused on the lack of food and describe the deaths of comrades. The cold did not go unnoticed. He wrote of sunbathing at forty degrees in May. He wrote of June temperatures well below freezing. After a storm and a very hard night outside he wrote of suicide: "Of all the days of suffering, none can compare with this. If I knew I had another month of this existence, I would stop the engine this moment."

Others had similar thoughts. "Schneider," Brainard wrote, "was begging hard this evening for opium pills that he might die easily and quickly."

It may go without saying that some of the men suffered from frostbite.

The absence of food was in a very real sense the result of the climate where they resided. The Arctic, despite seasonal and regional abundances of seals and whales and even caribou, is often desolate. And the cold forces one to eat more, to burn more fuel, further compounding the scarcity of

food. In a scientific paper written in 2002, it was estimated that the Greely expedition was two millio calories short of minimum survival rations. A diet of six thousand calories per day is not unusual for explorers in the polar regions. The calories are needed for both warmth and activity. This is as true fo animals as for humans. Bird feathers, when oiled, can no longer keep a bird's skin dry. For a while, a oiled bird will shiver to maintain its body temperature, but shivering requires food. Hypothermic bird die of starvation compounded by hypothermia, or hypothermia compounded by starvation. The same thing killed most of Greely's men.

Winfield Schley, who commanded the boat that picked up seven Greely expedition survivors in 1884, saw Greely through an opening in what was left of a tent. "It was a sight of horror," Schley wrote. "On one side, close to the opening, with his head toward the outside, lay what was apparently a dead man. His jaw had dropped, his eyes were open, but fixed and glassy, his limbs were motionless. On the opposite side was a poor fellow, alive to be sure, but without hands or feet, and with a spoon tied to the stump of his right arm."

❄ ❄ ❄

It is July thirty-first. Here, a mile from the Beaufort Sea, the thermometer struggles to break forty degrees. My companion, a botanist specializing in Arctic plants, wears rubber boots, wool socks, trousers made of synthetic wicking material, blue Gore-Tex overpants, a sweatshirt and a light jacket under a green plastic raincoat, gloves, and a fleece-lined hat. The wind blows at something like twent miles per hour. A blanket of fog, thick and damp, covers everything.

Paul Siple is credited with conceptualizing windchill factors in a report written in 1940 but held a a military secret until 1945. He hung water-filled plastic cylinders from a long pole at the newly established Bay of Whales Antarctica base and developed what became known as the Siple-Passel equation for calculating windchill. The windchill factor quantifies the amount of heat lost to wind combined with cold. It expresses what the temperature feels like when the wind blows. Heat lost to wind increases as the square of the wind's velocity. A day with forty-degree temperatures and twenty mile-per-hour winds feels the same as a still day at thirty degrees. It gets worse as it gets colder. At twenty-five degrees below zero with a thirty-mile-per-hour wind, it feels like sixty below. A common footnote on windchill charts warns that frostbite will occur within five minutes under these condition

Fog makes things worse still. The moisture in the air sucks heat away faster than dry air ever could. Fog chills to the bone. Meteorologists sometimes calculate the apparent temperature by combining the measured temperature, the wind speed, and the humidity. This is sometimes called "relative outdoor temperature." Most days, knowing this is no comfort whatsoever.

I wear rubber boots, cotton socks, jeans, and a light jacket. No overpants. No gloves. No fleece-lined hat. I suffer in the midsummer cold. Clothes make the man, or, at least, clothes make the man warm.

❄ ❄ ❄

Adolphus Greely lived to see his ninetieth birthday. He became the first American soldier to enlist as a private and retire as a general. He commanded the erection of thousands of miles of telegraph wires many of them in Alaska. He oversaw the relief effort following the 1906 San Francisco earthquake, and he was a founding member of the National Geographic Society. For a time, he ran the Weather Bureau, then part of the Army Signal Corps. He was in charge when the Blizzard of January 1888

swept through middle America.

Greely's bureau issued this prediction: "A cold wave is indicated for Dakota and Nebraska tonigh and tomorrow; the snow will drift heavily today and tomorrow in Dakota, Nebraska, Minnesota and Wisconsin."

In places, temperatures dropped eighteen degrees in less than five minutes. In Helena, Montana, the temperature dropped from just over forty degrees to nine below in less than five hours. In Keokuk Iowa, it dropped fifty-five degrees in eight hours. These temperatures do not include the windchill. They are straight temperatures, read from thermometers. Windchill temperatures were colder than forty below.

When the blizzard was over, people found cattle frozen in place, standing as if grazing, their once hot breath now formed into balls of ice around their heads. A government official estimated that something like 20,000 people were "overtaken and bewildered by the storm." Of these, about 250 die from hypothermia and complications of frostbite. The temperature dropped too far too fast. The snow blowing sideways, reduced visibility to what is called "zero-zero" — one can see zero feet upward an zero feet sideways. People staggered around blindly outside. Cattle, horses, and people, unable to see but knowing they had to seek shelter, wandered downwind. No amount of food would have helped the victims. They died from the cold alone. Because so many of the storm's victims were children, the blizzard became known as the School Children's Blizzard.

Sergeant Samuel Glenn, based in Huron, South Dakota, working for Greely's Weather Bureau, described the suddenness and severity of the storm:

> The air, for about one minute, was perfectly calm, and voices and noises on the street below appeared as though emanating from great depths. A peculiar hush prevailed over everything. In the next minute the sky was completely overcast by a heavy black cloud, which had in a few minutes previously hung suspended along the western and northwestern horizon, and the wind veered to the west (by the southwest quadrant) with such violence as to render the observer's position very unsafe. The air was immediately filled with snow as fine as sifted flour. The wind veered to the northeast, then backed to the northwest, in a gale which in three minutes attained a velocity of forty miles per hour. In five minutes after the wind changed the outlines of objects fifteen feet away were not discernible.

After the blizzard, a farmer named Daniel Murphy went out to his haystack. From inside the haystack, he heard a voice. "Is that you, Mr. Murphy?" The voice belonged to nineteen-year-old Etta Shattuck. She had staggered through the windblown snow and, as a last and only resort, had crawled into the haystack. She stayed there just over three days without food or water. Frostbite came on, as it always does, painlessly. There is a sense of cold and stiffness and numbness, but no pain. By the time flesh reaches a temperature of forty-five degrees, nerve synapses no longer fire. All feeling is gone. And then the tissue freezes. Ice crystals form first between the cells. Because ice excludes salts, the remaining liquid between the cells becomes increasingly salty. Osmosis draws water from within the cells toward the saltier fluid outside the cell walls. The cells become dehydrated. Proteins begin to break down. Ice crystals eventually form inside the cells themselves. The sharp edges of the ice crystals tear cell membranes. The flesh dies, starting with the skin. Usually the first skin to die is that of the fingers or toes or ears or nose. Death moves into the muscles, the veins, the bones. Whole limbs, once lively, freeze solid and are dead.

Etta seems to have crawled into the haystack headfirst. She prayed. She sang hymns. She listened

to the wind blow. She shared the haystack with mice. At one point, Etta felt the mice rustling through the stack and even nibbling at her wrists. She later explained that this was comforting rather than terrifying. It told her that she was not alone in the world. Because she had crawled in headfirst, her feet and legs were more exposed than her torso. They froze.

Saved from the haystack, Etta went through two rounds of amputations. The newspapers got wind of her, and for a short time she became something of a hero. The *Omaha Bee* set up "The Shattuck Special Fund."

"Miss Etta Shattuck," a reporter wrote, "the young school teacher who lost both limbs from the exposure in the recent storm, will be incapacitated for any service by which she may derive a living. is desired that $6,000 be raised." But infection set in. She was nineteen years old when she was caugh in the blizzard, and she died without seeing her twentieth birthday.

Never mistake frostbite for hypothermia. Frostbite freezes extremities, while hypothermia cools the body's interior. Humans function best at a core temperature of just under ninety-nine degrees. At windchills of minus forty degrees, with serviceable clothing, it is reasonable to expect the core temperature to drop at something like one degree every thirty minutes. When the core drops to ninety five, significant symptoms appear. People shiver uncontrollably. They become argumentative. They feel detached from their surroundings. As their minds slow, they become what winter travelers sometimes refer to as "cold stupid." They become sleepy.

A thirteen-year-old boy who survived the School Children's Blizzard later recounted his experience. "I felt sleepy," he said. "I thought if I could only lie down just for a few minutes I would be all right. But I had heard the farmers telling stories about lying down and never getting up again in snow storms. So I kept on, but I finally got to the point where I could hardly lift my feet any more. I knew that I couldn't stand it but a minute or two longer."

At a core temperature of about ninety-three degrees, amnesia complicates things. Do we turn righ or left? Did I put that glove in my pocket? Have I been here before?

At ninety-one degrees, apathy settles in. Muscles by now are stiff and nonresponsive. If one continues moving at all, one begins to stagger.

When the core temperature reaches ninety degrees, the body's ability to fight the cold diminishes and the core temperature tumbles downward. The heart itself becomes sluggish. Blood thickens. Lactic and pyruvic acids build up in tissues, further slowing the heartbeat.

It is possible to survive core temperatures as low as eighty-seven degrees, but only with rescue an rewarming. At this temperature, self-rescue is almost impossible. Hallucinations are common. The mind imagines warm food and dry sleeping bags. The ears might hear music. A survivor might repor looking down from above on his own struggling body, or he might remember strolling away from his own prone carcass in the snow. Victims at this point have crossed the line between cold stupid and what is sometimes called "cold crazy."

Just shy of death, victims may experience a burning sensation in the skin. This may be a delusion or it may be caused by a sudden surge of blood from the core reaching the colder extremities. The las act of many victims is the removal of their clothes — the ripping away of collars, the disposal of hats Doctors sometimes call this "paradoxical undressing."

A Nebraska newspaper explained why some victims of the School Children's Blizzard were missing clothes. "At this stage of freezing strange symptoms often appear: as the blood retires from the surface it congests in the heart and brain; then delirium comes on and with it a delusive sensation of smothering heat. The victim's last exertions are to throw off his clothes and remove all wrappings from his throat; often the corpse is found with neck completely bare and in an attitude indicating that

his last struggles were for fresh air!”

During the School Children’s Blizzard, a seventeen-year-old girl froze to death standing up, leaning against a tree.

Nebraska teacher Lois Royce wandered through the blizzard with two nine-year-old boys and a six-year-old girl. They could not find shelter. The girl was calling for her mother, begging to be covered up. The boys died. The girl lasted until daybreak. Lois eventually crawled to the safety of a farmhouse.

Johann Kaufmann, a farmer, found his frozen children after the storm. “Oh God,” he cried out, “is it my fault or yours that I find my three boys frozen here like the beasts of the field?” The bodies were frozen together. They had to be carried back to the cabin as one and thawed before they could be separated.

In Laura Ingalls Wilder’s *Little House on the Prairie*, the horror of blizzards is discussed by children. Laura is asked what she would do if caught in a blizzard. “I wouldn’t get caught,” she answers.

And Emily Dickinson, in “After Great Pain,” seems to have thought of hypothermia:

As Freezing persons, recollect the Snow —
First — Chill — then Stupor — then the letting go —

AUGUST

It is August second and sixty degrees. I watch a fisheries biologist wade into the Beaufort Sea. On and off, he has been wading into the Beaufort Sea for more than twenty years, collecting fish as part a long-term study. He wears chest waders, but the cold soaks right through. Even when he stays dry, the plastic fabric presses against his skin, feeling wet. At their best, waders in cold water give meaning to the word “clammy.” And at times the waders leak, or they are overtopped by a wave, or h steps into a hole and they fill up with ice water.

I sit in the Zodiac as he boards from water that reaches close to the top of the waders. He rolls across the edge of the Zodiac, leaning into the boat and straightening his legs, so that his feet are higher than his head. Water drains from the waders into the boat.

I tell him about the book I am writing. I tell him of my five-minute bath in the Beaufort Sea. He has this to say: “You should do a book called *Warmth.* You could do all the background research in Aruba.”

“What would be the fun in a book on warmth?” I ask. And then it occurs to me: fire walking.

❄ ❄ ❄

Some polar explorers stayed warm. Part of their secret was clothing. Richard Byrd, famous for a faile attempt to fly over the North Pole and for a successful flight over the South Pole, spent many months in Antarctica. It was during a Byrd expedition to Antarctica that Paul Siple hung his water-filled cylinders in the breeze and worked out the principles of windchill. In 1933, strapped for funds, Byrd overwintered alone in Antarctica. “Cold was nothing new to me,” he wrote, “and experience had taught me that the secret of protection is not so much the quantity or weight of the clothes as it is the size and quality and, above all, the way they are worn and cared for.” At sixty-five below zero, he wore, among other things, a mask. “A simple thing,” he wrote, “it consisted of a wire framework overlaid with windproof cloth. Two funnels led to the nose and mouth, and oval slits allowed me to see. I’d breathe in through the nose funnel, and out through the mouth funnel; and when the latter clogged with ice from the breath’s freezing, as it would in short order, I brushed it out with a mitten.” He wrote of walking comfortably outside, suited up, and he compared himself to a diver. This was in 1933, during a time when divers wore heavy canvas suits with brass and copper helmets bolted to the suits and weighted, metal-framed boots on their feet.

Another secret to warmth involved seeking help from the locals. This worked only in the Arctic, where there were local people from whom to seek help. Isaac Hayes walked away from his ship when

it froze into the Arctic ice in 1854. In general, he was scornful of the natives he encountered on his way south, whom he called "Esquimaux." He thought of them as savages, but he was not above accepting their hospitality. After taking refuge in a village, he wrote, "The hut was warmer by 120° than the atmosphere to which we had been so long exposed."

Patience to wait out the cold played a role in survival, too. Fridtjof Nansen's writings, though the were not intended to do so, make a mockery of the suffering of the likes of Scott and Greely and Bering. Nansen, in 1888, was the first to cross the Greenland ice sheet. He did it on skis. Later, he thought it reasonable to intentionally freeze his boat into the pack ice and let the drifting polar ice carry him across the Arctic. In 1893, he sailed from Norway in the *Fram*, a vessel not much bigger than a large yacht. He traveled with thirteen Norwegians, because, he joked, only Norwegians could tolerate one another for month after month on a boat drifting with the pack ice. A year and a half afte freezing in, Nansen and one of his men left the *Fram*. Apparently at least in part out of boredom, they headed north with three sleds, two kayaks, and twenty-eight dogs. After three weeks, Nansen was within four degrees of the pole, a new record, but there he turned. Heading south, the two men over-wintered on an island. They dug a hole three feet deep, which would have meant chiseling through permafrost with the consistency of hardened concrete. They put stones three feet high around the hol and then roofed it with walrus hides and snow. They laid in game, mostly bear.

Nansen and his companion gained weight that winter. Other expeditions at the time, if they went well, were at best exercises in survival. Fourteen years earlier, Lieutenant George De Long had penne his last journal entry in Siberia, and nine years earlier Greely had barely escaped alive. But Nansen wrote of shooting stars and "lovely weather." To ease the boredom, he and his partner took long walk in front of their hut. A playful arctic fox amused them and developed a habit of stealing from the camp. Its thefts included, oddly enough, a thermometer. Nansen wrote, "There is furious weather outside, and snow, and it is pleasant to lie here in our warm hut, eating steak, and listening to the win raging over us." They slept to a point approaching hibernation, to a point at which sleeping became a art. "We carried this art," Nansen wrote, "to a high pitch of perfection, and could sometimes put in as much as 20 hours' sleep in the 24."

❄ ❄ ❄

It is August eighth. I stand in a weed-choked lot just outside Fairbanks, Alaska, one hundred miles south of the Arctic Circle. It is close to sixty degrees. A giant air conditioner drowns out the noise of traffic, wind, and birds. In front of me, built into the side of a hill, is a shed, painted brownish red, a color marketed as redwood but looking entirely unnatural here among the spruce trees. A door leads into the shed and from there into the hillside itself.

This is the permafrost tunnel, built by the U.S. Army Corps of Engineers in the 1960s to test tunneling equipment. The idea was to bore into frozen hillsides, perhaps turning them into missile silos and bunkers. Cold War thinking, so to speak. Now the tunnel is used for research and education. A worn display panel shows visitors a picture of a very calm Dwight D. Eisenhower next to Nikita Khrushchev, whose fist is raised. I am here with a Russian permafrost expert based at the University of Alaska. Pointing out the photographs of Eisenhower and Khrushchev, he laughs at the way the world has changed.

The hill itself is of loess —finely ground particles originating when rocks were pulverized by massive rivers of ice in the Brooks Range, north of here. This grinding goes on today under what is left of the glaciers, but most of it occurred when the glaciers were more extensive, from seventy

thousand years ago to a mere ten thousand years ago, and before that, on and off for two and a half million years. The ice, sometimes miles thick, flowed down hills and across valleys, carrying with it stones and boulders and rocks. The bottom of the glacier, with its load of rock, acted as a massive, slow-moving mill, reducing granite mountainsides to dust as fine as flour — the same stuff that toda paints the water of glacial lakes azure. But when the glaciers pulled back, the flour was everywhere. Gales blew where warming ground met glacial ice. The gales picked up the flour, scattering it throug central Alaska, restacking it in drifts that became hills.

A walk into the permafrost tunnel is a walk through time. The lighting, the air-conditioning system, the signs, the very feel of the place speak of the Cold War. The sweeping scars of the tunneling machine, now decades old, remain frozen in place. And the walls themselves range to more than forty thousand years old. The walls of this tunnel — the earth of this hill — have been frozen solid for forty thousand years.

Frozen soil is not a rarity. Something like one-fifth of the world's land area lies within the permafrost zone. Poke a steel rod into the ground in northern Alaska, and you will hit frozen ground. The same rod will hit frozen ground in northern Russia, northern China, northern Norway, Iceland, a Greenland. It will hit frozen ground on certain mountaintops at the latitude of California. It will hit frozen ground in parts of Patagonia. Late in the summer, the rod will penetrate eighteen inches, thirty inches, three feet, and then hit what feels like bedrock. But it is a bedrock of frozen sand or gravel or fine glacial flour, glued together by ice. In some places, three-quarters of the soil is in fact frozen water. Put a building on this stuff, heat the building and warm up the ground, and the ice will start to melt.

What makes this tunnel unusual is that the government dug into the frozen ground, then kept it frozen. In summer, the massive air conditioner keeps the tunnel chilled near its entrance, where warm drafts sneak past doors. The earth here is like a giant cooler, its outer layers insulating its inside, keeping the tunnel walls in the low twenties. In these latitudes and farther north, the surface expression of frozen ground is visible everywhere, in the form of polygons and frost boils and slumped ground. Here you can walk right through that frozen ground. You get the worm's-eye view.

The place stinks. It is a forty-thousand-year-old smell of mixed mold and musty dirt and cold, something like the smell of a refrigerator that has gone too long unopened. The tunnel is twenty feet diameter and roughly round in cross section. One passage leads back into the hill more or less horizontally, while another slants downward. We head in horizontally, taking advantage of a metal walk-way. Roots stick out from the walls and ceiling. It is easy to imagine that these roots are alive, reaching down from the birch and alder trees growing on the hillside. But in fact we are well below th root zone. Ten feet beneath the surface, the ground never thaws, and living tree roots do not penetrate into permanently frozen ground. The roots in the tunnel walls are the frozen remains of Pleistocene plants. And what is this? The bones of a long-extinct steppe bison: a jawbone, a femur, a vertebra. In the wall, a horn stands frozen in time. The steppe bison was common here thirty thousand years ago but has been extinct for thousands of years.

The Russian tells me of plant material found in the tunnel that was still green after thousands of years. Grass had been covered with snow in a summer blizzard, and then the snow was buried under blowing soil. Likewise, the bison bones had been buried by the blowing loess, preserved for thousand of years. Occasionally, whole animals, flesh intact, are preserved in the permafrost. In 1979, a Fairbanks gold miner found a frozen steppe bison. That is to say, he found not only bones and teeth but a frozen carcass complete with skin and muscles and hair. Claw and tooth marks show that it was killed by an extinct lion. It had frozen so quickly after its death that scavengers could not pick it to

pieces. In the holes left behind by the lion's teeth, coagulated blood remained frozen in tiny pools. Shortly after the kill, or during the kill itself, snow may have been falling. The lion may have fed on the carcass for several days or even weeks but abandoned it before spring, leaving meat and flesh and bones behind. One can imagine the lion wandering away, overtaken and bewildered by blowing snow. At first the snow drifts against the carcass. Later, loess carried by wind or a landslide settles on top of the snow. The dead steppe bison is buried. A new layer of permafrost forms. Years pass. Miners dig into the icy ground. A university professor becomes involved. Carbon dating of a piece of skin shows that the bison died thirty-six thousand years ago. The carcass stands today in a glass case at the Museum of the North in Fairbanks, resurrected, looking more like a Texas longhorn than the modern bison of the Great Plains.

We walk past and through different features of frozen ground. I stand beneath an ice wedge — the same sort of ice wedge that forms polygons in the ground farther north. Near Prudhoe Bay, the ground is laced with these things, but they are visible only in their effect on the ground's surface. If the first few feet of soil around Prudhoe Bay were magically removed, the ground would become a honeycomb of ice. The soil, intact, obscures this reality. Here, underground, I can see the wedges themselves. The ancient ground expanded in summer and contracted in autumn, opening cracks. The cracks filled with water, and the water froze. The cycle was repeated again and again. And then the ice wedges were buried under the blowing loess that would become the walls of this tunnel. Looking at an ice wedge in the wall of the tunnel, I see a record of the process. Sediment tracks run up and down its body, marking each year's sequence of cracking and freezing, reminiscent of tree rings. The wedge is more than four feet wide at its top. Conservatively, it took hundreds of years to form.

Water is strange stuff. Most substances, when cooled, contract. This is why thermometers work: mercury shrinks as it cools and expands as it warms. Warmth makes the molecules in a substance move faster. They dance around, bumping into one another. As the temperature increases, they dance faster, and when they bump into one another, they push harder. They need more space. A cooler temperature means slower movement, softer collisions, and less space. This holds true for water, but only to thirty-nine degrees. After that, the water molecules start to line up. The water thickens. Hydrogen atoms in one molecule attract oxygen atoms in others. The process of crystallization begins. At thirty-two degrees, the water starts to freeze. The molecules line up like tiny soldiers in formation with orderly space between them. Newly frozen water is nine percent bigger than liquid water. Once frozen, if it continues to cool, expansion stops, and like most substances it shrinks.

Small caves and hollows line the tunnel's walls. The ice holding the walls together has not melted but some of it has sublimated — disappeared into the air as vapor without ever going through a liquid phase. The walls are frozen and steaming at the same time. This is true, too, of snow and ice at the surface — in glaciers, in freezers. The vaporization of ice — evaporation from the solid phase — is the basis of the freezer burn that ruins frozen meat and fish.

Among the ice wedges, veins of ice run horizontally along the tunnel walls like veins of coal in a Virginia mountainside. The Russian calls this "segregation ice." It forms in keeping with another strange property of water: liquid water in finely grained soil is sucked toward colder zones in the soil. We stare at a vein of segregation ice, a one-inch-thick stratum of what looks like almost pure ice.

"People call it cryogenic suction," the Russian says, "as though that explains everything. But cryogenic suction is a very complicated mechanism." In freezing soils, liquid water adheres to soil particles, forming thin layers of water around each grain of soil. Molecules are bound more tightly to thin layers of water than to thick layers of water, and thin layers of water tend to attract molecules of water from nearby thicker layers. When soil starts to freeze, the layers of liquid water turn to ice and