Mass Destruction

THE MEN AND GIANT MINES THAT WIRED AMERICA AND SCARRED THE PLANET

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FOR CHERÍ, CARINA, AND DANIEL

TWO

Between the Heavens and the Earth

The operations of nature, mechanical and chemical, are supplemented by those of man, who is a great mimic.

—T. A. Rickard

Thus the heavens and the earth were finished . . .

—Genesis 2:1

The autumn of 1902 in the Deer Lodge Valley was like many in southwestern Montana before and since. The days were mostly dry and warm, the nights chilly and cloudless. Relatively little rain fell to wash the dust off the quiet farming valley, and the hay and other crops grew predictably slower as the daily hours of sunshine grew shorter. This was the typical cycle of autumn, one that the ranchers and farmers had adapted to and learned to plan for during the half century since the first Euro-Americans arrived in the valley in the 1850s. What they did not know until much later was that these welcome and predictable seasonal patterns were now conspiring with poisons in the air to make their lands increasingly dangerous.

Deer Lodge rancher Nick Bielenberg was among the worst hit. He watched with growing alarm and frustration as his once vigorous herds of cattle, sheep, and horses suddenly began to sicken and die. The owner of one of the oldest and most successful ranches in the valley, Bielenberg had never seen anything like this. In the course of only a few weeks, more than

a thousand head of cattle, eight hundred sheep, and twenty horses were dead. When he talked with neighbors, he learned that many were experiencing similar stock deaths. In different circumstances, Bielenberg and the other ranchers might have blamed some exotic plague or the introduction of a new poisonous herb to the valley. In the autumn of 1902, though, a more obvious explanation lay on the far southwestern edge of the valley where the four tall stacks of the Anaconda Company's brand-new Washoe smelter sent a steady stream of stinking yellow smoke rolling out over the valley.[1]

So began the "smoke wars," the battle between the Deer Lodge Valley farmers and the Anaconda over whether the smelter smoke was damaging crops and livestock, and if so, what should be done to solve the problem. The Anaconda had built its first copper smelter in the sparsely populated Deer Lodge Valley in 1884, attracted to the area for the abundant fresh surface water available from Warm Springs Creek. The Washoe was fed by company ores from giant underground mines in nearby Butte, shipped to the smelter city over a dedicated rail line. The copper deposits were rich and astonishingly big, to an extent rivaled by only a handful of others in all of human history. The work of the Anaconda's corporate engineers had made much of this natural wealth available for exploitation, and the thousands of workers who labored underground pushed the mines deeper and wider every day.

By the time Nick Bielenberg's cattle began to sicken, collapse, and die, Montana had been a state for not much more than a decade. Nonetheless, this remote and sparsely settled region was home to one of the most advanced examples of modern mining and smelting technology in the world. The sheer size and scope of the Anaconda operations would present daunting challenges to the mining engineers, and their allied experts, as they attempted to understand and control the poisons killing Bielenberg's animals. Ultimately, their efforts would fail, though they made significant progress before the limits of their technology, a ruthless corporate drive for profit, and a ravenous American demand for copper undermined earlier successes. The result would be the dead zones, immense areas of environmental and human destruction. But that sad outcome was still several decades in the future.

Before then, the mining engineers approached the challenge of the Deer Lodge Valley smoke problem with optimism, confident that they could and must find a solution. To not mine, to abandon that colossal hill of copper ore, was simply not an option. In the minds of the engineers, as in the minds of most Americans, copper was the metal of modernity, the shiny red stuff that was helping to take the nation into a bright new age of prosperity and ease. After all, the man many believed to be the greatest inventor in the history of the world had made it so.

A BRIGHT LIGHT FROM A DYING STAR

The great breakthrough came on October 21, 1879, or so the popular story goes. That day one of Thomas Edison's Menlo Park laboratory assistants took a glass globe with a thin carbon filament suspended in a vacuum and connected it to the testing apparatus. With the close of a switch, electricity surged from a power generator, through a circuit of wire, and up into the bulb. It glowed—as was expected. Edison and his assistants had done this same experiment countless times before with platinum filaments. All of these earlier bulbs had also glowed, but the platinum filaments quickly burned out or gave only feebly flickering light. Edison's decision to try a new filament made by carbonizing a strand of common sewing thread was an act of creative desperation. Other inventors had tried carbon filaments before and failed. They, however, had not had Edison's advanced vacuum pumps, and the inventor hoped that a better vacuum inside the bulb would make all the difference. It did. The new bulb produced a steady glow of light, about as bright as the gaslight fixtures common then to American shops and homes. More important, the new filament burned nearly fourteen hours. After several months of work, Edison and his team found another type of carbon filament that burned for 1,200 hours. At last this was the long-lasting incandescent light bulb Edison had been searching for, the essential element in his plans to create an electrically powered lighting system cheap and reliable enough to replace gaslights.[2]

In reality, Edison's "eureka moment" was not quite so clear and dramatic. Testing of a carbon filament bulb stretched over several days, and Edison and his team only gradually realized they had found the answer. Historians of technology also know that Edison's "invention" was an important but only incremental improvement on the work of several generations of previous inventors. The carbon-filament vacuum bulb had been "under development," one might say, for nearly four decades by the time of Edison's 1879 experiments.

Most important, though, the traditional popular focus on Edison's light bulb tends to miss the significance of his true accomplishment: the creation of an entire system for generating and distributing electricity, without which the most advanced light bulb in the world was a useless brittle

sphere of fancy glass and wire. As the historian Thomas Hughes argues, Edison's dynamos (electrical power generators) and his parallel-distribution wiring system were every bit as important as the light bulb itself.[3] Though rarely remarked upon by the public, both then and now, what was equally striking that day in October of 1879 was not just the light bulb but the fact that Edison was able to "plug it in." Of course, that first test bulb did not yet have the now familiar metallic screw base, whose brilliant simplicity would eventually spawn an entire genre of jokes. Rather, the bulb had two strands of insulated wire running down from the filament and through the neck of the glass containment vessel. To "plug in" the bulb, one of Edison's team secured the wires to a circuit that connected the bulb to the lab's newly completed high-voltage dynamo. Powered by a small coal-fired steam engine, the dynamo charged the wire circuit. When the researcher closed the switch, the circuit was completed, the electricity flowed, and the light bulb was able to glow for those fourteen revolutionary hours.

Although other metals like iron were in use as well, copper was critical throughout Edison's electrical power generating, distributing, and testing apparatus. The Menlo Park electrical system was really a small dress rehearsal for what was soon to come. Three years later, Edison installed his first electrical generating and distribution system on Pearl Street in lower Manhattan. A twenty-seven-ton "Jumbo" dynamo (named after P. T. Barnum's famous elephant) generated the electricity through a system of heavy copper bars and brass (an alloy of copper and zinc) discs that rotated around a magnetic core. Edison distributed 110-volt direct current power over several blocks via nearly twenty miles of thick copper wires threaded through underground conduits. Eventually, the Pearl Street Station supplied an area of about one square mile with enough power to light more than ten thousand bulbs. Customers liked Edison's soft, clean, and safe electric light, but the Pearl Street operation remained unprofitable for almost five years, in large part due to the immense cost of the heavy copper wire.[4]

It was fitting, then, that Edison sent the first-ever electric power bill, for $50.44 (a considerable sum at the time, equivalent to perhaps $1,000 in modern U.S. dollars), to the Ansonia Brass and Copper Company. A Connecticut manufacturer of copper and brass wire, tubing, and other materials, Ansonia had a New York office a few blocks from Edison's Pearl Street Station.[5] Ansonia had also provided Edison with some of the copper used in his Menlo Park experiments, and Edison had encouraged the company to improve its manufacturing methods in order to produce copper wire with high levels of uniform conductivity. In 1883, Edison provided Ansonia with a wire testing apparatus and the advice of one of his electrical experts, and he credited this for the company's development of a reliable means of making high-quality copper wire for the electrical industry.[6] With the Pearl Street Station up and running, the Ansonia managers surely understood that Edison's new electrical light and power system promised to create a major new source of demand for their copper products.

If electricity gave birth to the modern age, then copper was its midwife—or at least a very supportive birthing coach. Five years after Edison opened the Pearl Street Station, Frank Sprague built an electric streetcar system in Richmond, Virginia, creating a completely new consumer market for electricity. By 1902, the nation had 21,920 miles of electrified streetcars, most of them fed by copper wires and using copper-based electric motors. Manufacturers began to realize the benefits of electric lights and motors in earnest around the turn of the century, propelling demand beyond the consumer markets. With the development and eventual dominance of George Westinghouse's alternating current power (relegating Edison's prized direct current to a secondary role), centralized generating plants began using thick copper wires to transmit power over long distances. The growth cycle even fed back on itself as copper manufacturers used electrolytic refining to provide cheaper, purer, and more highly conductive products.[7] Between 1880 and 1914, the use of electricity in manufacturing went from essentially zero to almost nine million horsepower of installed equipment.[8]

Other markets for copper grew as well. By the mid-1920s, the Bell Telephone System had already bought more than seven hundred million pounds of copper for constructing its nationwide phone network.[9] Warfare also proved to be an especially voracious consumer. World War I sparked an enormous new demand, though it paled in comparison to the subsequent conflict. During World War II, eight hundred pounds of copper went into a typical tank, a ton into a large bomber, one thousand tons for a battleship. Brass shell casings demanded copper and zinc. A 37 mm antiaircraft gun could use a ton of copper during twenty minutes of sustained action. The machine guns of a fifty-plane squadron might shoot seven tons of copper in just sixty seconds of battle.[10]

Light and power, factories and streetcars, telephones and tanks—copper was essential to them all, not to mention the many new electrical devices like vacuum cleaners and blenders that were colonizing American homes during the first half of the twentieth century. Indeed, so many devices and processes depended on electricity during this period that per

capita copper consumption became a fairly accurate indicator of national economic growth and modernization. Despite frequent turbulence in markets and a sharp drop in demand immediately after World War I, per capita copper consumption in the United States and Western Europe increased rapidly throughout the first decades of the twentieth century. Coal, iron, and steel may have been the building blocks of the world's first industrial age, but copper was at the electric heart of the second. Daniel Jackling, the inventor of the mass destruction technology that would give the world so much cheap copper, praised the metal that had made his fortune in a 1937 article. "Copper is verily one of the world's most essential metals," he writes. "Linked intimately with the production and application of electrical energy, copper plays a vital role in modern life. . . . Thomas Edison's incandescent lamp was the invention that started the tremendous expansion of that industry. With the widespread use of electric power have come most of our modern conveniences—the telephone, automobile, radio, refrigerator, washing machine, water heater and, lately, air-conditioning equipment."[11]

Many Americans also believed that copper would help the nation escape the grime and pollution that had plagued nineteenth-century industrialization. Copper would help usher in a clean, modern, electrically powered world that would provide all the conveniences of technology while also maintaining a healthy and morally uplifting environment. As Watson Davis notes in his 1924 hagiography of the metal, "If the cloud of smoke is to be lifted from our cities, if our factories are to be made clean and our homes-convenient by the substitution of electric power for coal burning, it will be by aid of this humble element."[12] Even Lewis Mumford, who was at times a fierce critic of modern technology, initially praised the revolutionary potential of copper and electricity. In his classic 1934 history of Western technology, *Technics and Civilization*, Mumford argues electricity would help give birth to the "neotechnic" phase of civilization, an era with all the benefits of modernity but the "clear skies and the clean waters" of the preindustrial age.[13]

Mumford's sunny views stemmed in part from his belief that hydropower could meet much of the nation's demand for electricity. Edison's Pearl Street Station had used the dirty coal-fired steam engines of the past—what Mumford called the paleotechnic age. But many assumed the future of electricity would be hydropower facilities like those constructed in the late nineteenth century at Niagara Falls. There the diverted force of the river drove immense underground dynamos, and copper wires carried the power to distant cities. The modern miracle of hydropower turbines and long-distance transmission almost seemed to promise a belated return to the idyllic era of the pastoral water mill.[14] Copper, the mining engineer Charles Henry Janin enthused in 1924, was "taking the waterfall to the heart of the city; one instant tons of water drop; the next, tons of machinery hum."[15]

Copper mining companies often played important roles in the development of electric power generation and distribution, particularly in the West. Daniel Jackling helped found the Utah Power & Light Company, which initially provided power for the big new electric shovels in the Bingham Canyon pit but soon became Utah's main electric power company.[16] In Montana, the president of the Anaconda, John D. Ryan, founded the Montana Power Company that dominated electrical power generation and distribution in the state until the 1990s.[17] As a 1912 story in the *Salt Lake City Tribune* rightly observed, the Utah and Montana copper mining interests "paved the way for [copper], and by the development of their respective electric power fields they have made assured an adequate supply of power."[18] A wise move as it turns out, since by the late 1950s the Bingham Pit would be by far the largest single consumer of electric power in Utah. The pit shovels, trains, concentrators, and other machines consumed an astounding 650 million kilowatts of power every hour—roughly the amount used by a city of one hundred thousand.[19]

Americans used copper (and its common alloys, brass and bronze) in thousands of other ways, from Model T radiators to household plumbing. But it was copper's intimate pairing with electricity that drove much of the growth in demand during the first half of the twentieth century. That partnership hinged primarily on a seemingly trivial atomic quirk. Copper is a basic building block of the universe, one of the ninety-two atomic elements that occur naturally on earth (though some argue the number is slightly higher or lower) and from which all other substances are made. Its chemical symbol is Cu, an abbreviation of its ancient Roman name, *cuprum*. On the familiar chart of the Periodic Table of Elements that hangs in nearly every American chemistry classroom, copper appears as number 29. This atomic number helps to explain copper's unusually high ability to conduct electricity. The 29 indicates that each copper atom has twenty-nine positively charged protons in its nucleus and twenty-nine negatively charged electrons orbiting around the nucleus. Because of the way the electrons are packed in around the atomic nucleus, twenty-eight of them are in the lower electron "shells" closest to the nucleus. That means the twenty-ninth electron sits by itself in copper's outermost atomic shell,

where it can be easily stripped off. This makes copper a wonderful source of moveable electrons. When electric current "flows" through a copper wire, the outermost electron jumps easily to the neighboring copper atom, which in turn shoves another electron down the line, and so on. The effect is something like pushing on one end of a long line of railcars. Each electron only moves an infinitesimally small distance, yet this line of colliding twenty-ninth electrons can transmit an electrical charge over very long distances almost instantaneously.

Because of its durability and resistance to corrosion, copper was also the metal of choice for steam pipes, plumbing, automobile radiators, and other heat exchange devices. It is very malleable, and manufacturers could easily form copper into a wide variety of shapes. Copper's high strength under tension also made it well suited for wire strung between power poles. By comparison, aluminum was lighter and cheaper but had only about 60 percent of the conductive capacity of copper and far less tensile strength—a serious shortcoming when a power wire sometimes had to span long distances between poles. Thicker aluminum wires could make up for the loss in conductivity, and the wires could be buried instead of strung from pole to pole, but the cost and disruption to built areas would have been much greater. Almost as if by design, copper seemed uniquely suited to serve the growing demands of national electrification.[20]

Immediately beneath copper in the same Periodic Table column are silver, number 47, and gold, number 79. Silver and gold are also superb electrical conductors for the same reason as copper: both metals have a single easily moveable electron in their outermost atomic shell, which is partially why they share a column on the Periodic Table (the "periodic" suggests these intriguing patterns of similarities in the elements that had long been remarked though not always fully understood). Edison did not use gold in his Menlo Park wires or silver in his Pearl Street Station dynamos for the obvious reason: gold and silver were expensive precious metals, whereas copper was a much cheaper "base" metal. To wire lower Manhattan with silver would have cost a fortune. To use gold would have probably sparked a bizarre New York "gold rush" with hordes of "eighty-twoers" covertly tearing up the pavement to mine Edison's precious wire. This distinction between precious and base metals, though, is substantially a function of relative scarcity and cultural fashions. If copper had been as rare as silver or gold, its culturally determined value might well have been as great or even greater. Compared to truly abundant mineral elements like aluminum and iron, copper actually is quite scarce. Geologists estimate that about 8 percent of the earth's crust is aluminum and 4 percent iron. Copper, by contrast, makes up only 0.01 percent of the earth's crust, or a concentration of about 50 parts per million (ppm). Even so, copper is still some seven hundred times more abundant than silver (0.07 ppm) and about forty-five thousand times more abundant than gold (0.0011 ppm).[21]

The crustal scarcity or abundance of all but the lightest elements (which scientists believe were created in the Big Bang some ten to twenty billion years ago) is in part a product of the stars, the original furnaces in which all the metallic elements were forged. Through a process called nucleosynthesis, the tremendous heat and pressure inside stars fused together the lighter elements to make heavier elements. Astronomers have long known that stars between one and eight times the mass of the sun gradually built up heavier elements in their cores over the course of millions of years. The heaviest of these is iron, and its relative abundance in the Milky Way (and on earth) is a product of this slow process of fusion in countless stars across the galaxy over the course of billions of years. Internal stellar fusion, though, can only create elements up to the atomic number of iron, 26. The nucleosynthesis of the remaining sixty-six elements that occur naturally on earth—including copper—thus must have resulted from even more extreme conditions than stellar atomic fusion.

Until very recently, scientists were uncertain how stars created the copper on earth. They knew that copper's close periodic cousins, gold and silver, were formed when massive dying stars blew themselves apart as spectacular supernovae. However, astronomers found that the distribution of copper in stars of different ages was not what it should have been if the metal was created by big supernova explosions. For years, astronomers debated the heavenly origins of copper. Some argued the metal must have been born in very big stars. Others were partisans of white dwarfs, dense "white-hot" stars smaller than the earth itself. Finally, a paper published in 2007 by two Italian astronomers appeared to have settled the debate. Most of the copper in the Milky Way, Donatella Romano and Francesca Matteucci conclude, arose in "supergiants," the most massive stars in the universe. Supergiant stars have ten to seventy times the mass of the sun, and they can be five hundred or even a thousand times bigger in size. As these supergiants consume the vast amounts of atomic fuel needed to keep them burning, they eventually reach a stage where neutrons are created. Unlike the supernova explosion with its immense sudden shower of neutrons, however, the supergiant core only produces neutrons very slowly. Copper,

the astronomers argue, is created during this slow process of supergiant neutrons colliding with iron atoms and gradually heavier elements.[22]

Copper, gold, and silver are all the products of massive stars, then. Copper, however, was only forged over the course of millions of years, while gold and silver were created in the flash of an eye during the intensely bright explosive moment of a star's death. Since supernova explosions only occur in the Milky Way an average of about once every fifty years, we are unlikely to witness the stellar creation of gold and silver with the naked eye. But on any clear winter's night, residents of the northern hemisphere can easily see examples of the supergiant stars where more copper is even now slowly being created. Two of the brightest stars in the well-known constellation of Orion are supergiants: Rigel at the lower right of the constellation and marking one of Orion's feet, and Betelgeuse at the upper left and marking his shoulder.[23]

The vast majority of the copper, gold, silver, iron, and other heavy elements in the earth's crust today came from these stellar processes. When these elemental stellar nurseries exploded, they ejected their stores of metals out into space at immense speed, sending them on long cosmic journeys. Some of this material eventually gave rise to the next generation of stars and other solar systems, including the sun and its companions. After the formation of the sun itself consumed the mass of material, a thin cloud of dust remained in orbit around the young star. Over the course of millions of years, these leftover dregs from the sun's creation gradually accreted into the rocky bodies that became the planets, moons, and asteroids of our solar system. With the minor exception of occasional contributions from meteorites and other captured space detritus, the earth obtained all of the copper it would ever have when the planet formed out of this cloud of dust from shattered stars.

That copper is more abundant than the "precious" metals of gold and silver is thus a mere happenstance of stellar nucleosynthesis: like the tortoise, the slow but steady copper won out over the fleet but unreliable hare. As noted before, though, the earth's cosmic inheritance of copper is still relatively meager: only one one-hundredth of 1 percent of the planet's crust. Had this tiny amount of copper remained uniformly distributed throughout the earth's crust, it would have had a density of about 50 parts per million—much too small to be profitably extracted by even modern technologies. However, over the course of millions of years, geological forces concentrated a portion of the earth's total allotment of copper in a relatively small number of sites around the globe. On rare occasions, these deposits are pure elemental copper, so-called native copper. Far more commonly, copper is found in combination with iron, sulfur, or other elements.

Two of the most commercially important copper minerals are chalcopyrite and chalcocite. Because they both contain sulfur, geologists refer to these minerals as sulfides. Chalcopyrite ($CuFeS_2$) is copper iron sulfide, a molecule in which one atom of copper is bonded with an atom of iron and two atoms of sulfur. Chalcocite (Cu_2S) has no iron, so it is simply copper sulfide. Chalcopyrite was the most important copper mineral in the Bingham mines. Chalcocite was very abundant in the Butte mines, though other copper minerals were also present, as well as significant amounts of silver, gold, and other metals. The presence of such unusually high concentrations of minerals at these two particular sites was the result of two interconnected geological phenomena: plate tectonics and hydrothermal deposition.

The Butte and Bingham deposits were created millions of years ago when drifting tectonic plates of the floating crust of the earth collided. These forces slowly raised up the chain of mountains we call the Rockies, and in the process brought molten rock magma containing copper and other minerals much closer to the surface than is typical. As water from the surface percolated down into the earth, it dissolved copper minerals from the magma. This superheated mineral-laden water was then driven back toward the surface, where it gradually worked its way into cracks and fissures in the rock above. When the water cooled, chalcocite, chalcopyrite, and other minerals were left behind, but now in concentrations far higher than in the original magma. At Butte, where the rock itself was badly fractured, the deposition took the form of easily recognizable veins of minerals. Subsequent surface erosion and chemical weathering also leached out copper at the surface and redeposited it in a superenriched zone of chalcocite. Beginning at about three hundred feet below the surface of Butte and extending down to over a thousand feet, this immense deposit of high-grade copper ore was a major reason (though far from the only one) that miners called Butte "the richest hill on earth." The processes that formed the Bingham chalcopyrite deposits were similar, but with a critical difference, and will be discussed in detail in chapter 4.[24]

That Edison—and soon after, much of the nation and the world—could use copper to generate, create, and harness electric power was thus the result of an extraordinary chain of natural phenomena. In his groundbreaking work of environmental history, *Nature's Metropolis*, William

Cronon argues that Americans did not so much create the wealth they exploited in the West as simply take advantage of the natural wealth that was already there. Nature, in other words, had already done much of the work. While Cronon focuses on organic wealth from forests and prairie grasses, the same point holds true for the West's inorganic mineral wealth. The story in this book is mostly about the human efforts to win copper from the earth and control the resulting pollution. But whether we admire or condemn these efforts, we should not forget that humans were merely tapping into much larger galactic and geological forces of copper creation, dispersion, and deposition that had been going on for billions of years. Seen in this light, the mining engineers who developed the means to extract copper ore from Bingham and Butte were not nearly as different as they liked to believe from all the other animals that depended on the earth's natural bounty to survive and reproduce.

Most mining engineers, of course, did not view their technological achievements quite so modestly.

RATIONALIZING SUBTERRESTRIAL BUTTE

Walk the steeply sloping streets of uptown Butte, Montana, today and the seemingly solid ground beneath your feet is something of an illusion. Over the course of nearly a century, miners excavated an extraordinary ten thousand miles of mine tunnels and shafts, leaving behind something more like termite-infested wood than terra firma.[25] Sometimes the filigree of rock gives way and the ground collapses. The residents of Butte have long told stories of animals and buildings swallowed up by subsiding earth, disappearing into the ground as if pulled down by the very demons of hell. As the immense masses of rock below settled and shifted, pavement cracked and water lines splintered like toothpicks.[26] Though the days of underground mining have long since passed, ground subsidence remains a serious problem in Butte. Developers are reluctant to build in certain parts of the city where the ground can literally drop out from under their investment. Many of the more dramatic stories of ground collapse are fanciful exaggerations, examples of how the citizens of Butte take a perverse pride in emphasizing the jagged edges of their city. In an early scene from the 1971 biopic of motorcycle daredevil and Butte native Evel Knievel, the film tries to convey something of Knievel's hardscrabble youth. Walking in the barren dusty moonscape of Butte's mining district, the boy "Evel" blocks a car as he dawdles in the middle of a dirt road. When the ground suddenly collapses under the car and its driver, he listens with placid indifference as the blare of the car's horn slowly fades into the dark depths below.[27]

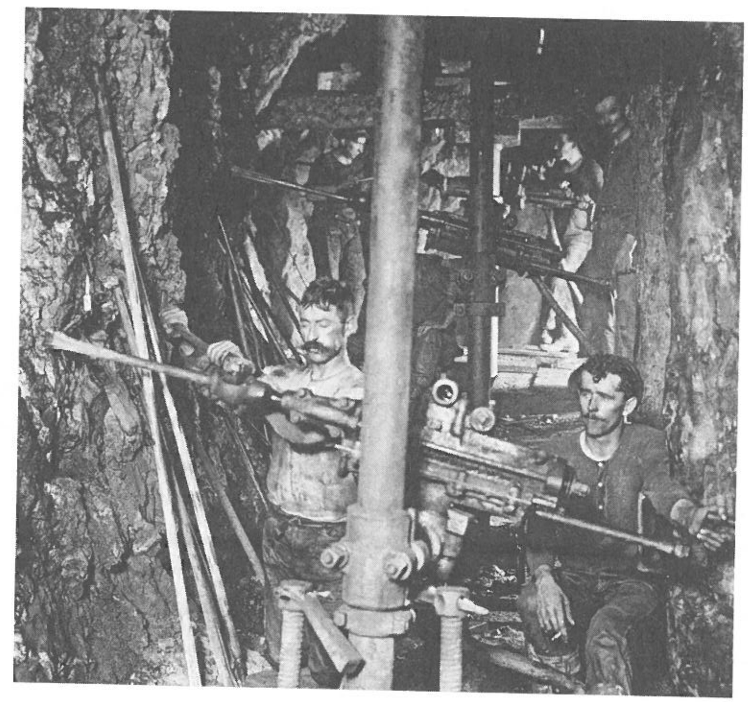
In Butte, the possibility that the subterrestrial will suddenly intrude on the terrestrial is always present. Usually, though, this underworld remains quietly invisible and largely unknown, except perhaps to the rapidly dwindling proportion of Butte's citizens who once actually worked in the underground mines. Merely being told of the reality beneath is of little help, as it remains difficult for "surface-lubbers" to envision or really even comprehend that the small city of Butte sits on the remains of an immense three-dimensional underground city that reaches more than a mile deep into the earth. Going into one of the few parts of the mines that are still accessible today is no help either. Being underground simply raises new barriers to seeing, since only a small section of the vast subterranean complex is visible at any one time. There are no "overlooks" for subterrestrial Butte, and no horizons or other fixed point of reference with which to get your bearings. Even the men who once spent many years laboring there only came to know a small part of the maze.

"Legibility," the political geographer James Scott reminds us, "is a condition of manipulation."[28] Any successful attempt to control and exploit a complex system, whether it be a subterrestrial mine or a terrestrial ecosystem, demands some means of taking its measure and mapping its essential characteristics. One of the greatest obstacles to large-scale industrial mining was developing the means for making the hidden underground world "visible." With improved maps and measurements, mining could be rationalized and systematized; obstacles could be overcome with powerful new machines and techniques. Gradually, the subterrestrial environment of the mine could be transformed into the physical embodiment of an "ideal" mine that had previously existed only in the heads of miners and mining engineers. During the late nineteenth and early twentieth centuries, American mining engineers did just that, creating an increasingly powerful array of techniques for measuring, engineering, and controlling complex underground spaces. As Rossiter Raymond, the secretary of the newly created American Institute of Mining Engineers, said in 1871, the goals of the profession were clear: "We want analysis; we want measurement; we want exact comparison; we want the universal recognition of the absolute value of the truth, and the relative worthlessness of anything short of it."[29]

In this adamant demand for analysis, measurement, and what Raymond considered "the truth" lay the seeds of both the mining engineers' modern

success in creating and controlling gigantic but comparatively simple subterrestrial environments and their failures in managing more complex terrestrial environments. The extreme expression of these ideas and techniques would be Daniel Jackling's open-pit mine at Bingham, a monument to the way in which modern rationality could sometimes become profoundly irrational.

Yet for all its power, the engineers' control of their underground environments was also flawed. Since at least the days of the ancient Romans, mine operators had pushed the limits of their technical abilities in order to make a profit from extracting minerals at ever greater depths. As mines began to sink thousands of feet below the surface, the problems of subterranean flooding, heat, and ventilation grew ever more challenging. The



4. Early twentieth-century miners drilling in the highly engineered environment 1,900 feet below the surface in Butte, Montana. As the Butte mines sank deeper, mining engineers created complex pumping, ventilation, and cooling systems that made it possible for humans to survive and work in harsh underground environments. *Courtesy Montana Historical Society Photograph Archives, Helena.*

mine engineer was increasingly required to become a type of early environmental engineer, developing complex technological and managerial systems to meet the basic biological needs of the human beings who actually worked in the deep underground. As with the mines themselves, these early life support systems were an extraordinary engineering achievement, and they eventually permitted miners to survive and work in the harsh environments more than a mile beneath the earth. However, when complex envirotechnical systems failed, the consequences could also be disastrous. In this, the triumphs and the disasters of engineering mining ecosystems anticipated those that would meet later attempts to engineer surface ecosystems.

Though the United States had long engaged in coal mining, and miners had developed underground lead deposits in Illinois and Missouri, large-scale hard-rock mining operations did not become common until after the California Gold Rush of 1849. Of course, the early California gold miners came in search of easily obtained placer deposits, not hard-rock lode deposits. These rich deposits of gold dust and nuggets were found along the courses of rivers and creeks, and they quickly played out. Most of the unskilled miners gave up or headed elsewhere in search of the next big strike. In the decades to come, Nevada, Colorado, Montana, and other western territories would all have their brief moments as the next big placer bonanza. A few of the more ambitious California miners managed to extend the life of the placer mines through hydraulic mining, a powerful early mass-mining technique the Romans had used on Spanish placer deposits two millennia before. Hydraulic miners dammed a creek or river to build up a head of water pressure and then channeled the water down through a heavy fabric hose to a cast-iron cannon, or "monitor." As the water entered the narrow barrel of the monitor, it built up enough pressure to shoot out of the nozzle at speeds of over one hundred miles per hour. Miners scoured away entire hillsides of dirt and gravel with the high-speed jets of water, capturing the relatively small amounts of placer gold by channeling the runoff down long sluices.[30]

As the historian Andrew C. Isenberg notes in his pathbreaking ecological history of California industrial mining, the advent of hydraulic mining there signaled a shift to the capital-intensive industrial mining that would dominate much of the West for the next century. Whereas the forty-niners had used simple tools to develop placer mines, the hydraulic miners used

costly tools and large-scale engineering techniques. Only the few who had access to scarce outside capital could afford to develop such mines, and increasingly the men who worked them were wage earners rather than owners.[31] The powerful but imprecise methods of hydraulic mining also exacted a heavy toll on the California environment, washing away thousands of acres of forests and soil. The silt generated by the mines choked downstream rivers, destroyed fisheries, and covered good farmland with thick layers of unproductive sand and gravel. As Isenberg rightly argues, hydraulic miners shifted much of the cost of industrial mining to the environment, as would be the case with the subsequent development of industrial logging, ranching, and farming in California.[32]

This practice of achieving industrial speed and efficiency by transferring costs to the environment would reach its extreme expression half a century later in the mass destruction techniques pioneered by Daniel Jackling at his Bingham Pit. Jackling's nonselective copper mining technique bears a familial resemblance to hydraulic gold mining. However, the engineering challenges to open-pit low-grade copper mining were far greater than those posed by hydraulic mining. Thus, a more significant technological precursor to Jackling's pits was the development of deep hard-rock mining operations. Most placer miners had neither the desire nor the ability to find and extract the gold from its original source in the Sierra Nevada, the so-called mother lode. But as with the hydraulic miners, a handful pioneered the early efforts at hard-rock mining. The most significant of these early mines was the Comstock Lode, an immense aggregation of silver and gold deposits on the eastern slopes of the Sierra Nevada near Lake Tahoe. To mine the Comstock deposits demanded a quantum leap in technology and capital well beyond even the most ambitious hydraulic mining operations.

Unfortunately, few Americans in the mid-nineteenth century had any experience in hard-rock mining. The most successful mine owners and operators sought the aid of European miners and mining engineers, many of whom had learned their craft in the mines of Europe and England. Such was the case with the early Comstock miner George Hearst, a man whose own considerable fame was later eclipsed by that of his son, the newspaper baron William Randolph Hearst. Orson Welles drew loosely on William Hearst's life in writing his 1941 film *Citizen Kane*. Welles offered a Colorado gold mine as the basis of the Kane family fortune, which seemed an obvious allusion to the Nevada silver mine that was the source of Hearst's. Like many California miners, Hearst initially tried his luck with the placer gold mines and found little success. In contrast to the vast majority of the Gold Rush miners, though, Hearst knew something about lode mining, having worked in the lead mines near his Missouri home. When he heard reports of a rich gold and silver lode deposit on the eastern flanks of the Sierra Nevada, Hearst rushed to the site and established several claims. Joined by his financial partners, James Ben Ali Haggin and Lloyd Tevis, Hearst began development of the Ophir mine on the Comstock Lode in 1859.[33]

Technical obstacles quickly emerged. At only fifty feet below the surface, Hearst's miners hit groundwater and the mine began to flood. Fortunately, Hearst and his partners had the capital to purchase the first steam-powered pump to dewater the Comstock Lode, and they then paid a good deal more to have it hauled by wagon from San Francisco. An eight-inch pump capable of generating forty-five horsepower, the machine was the direct descendant of the early rocking beam steam engines pioneered in the Cornish copper and tin mines of England over the previous century. At 175 feet, Hearst and his miners faced an entirely new problem. Despite its being a "hard rock" mine, the ore and surrounding country rock on the Comstock Lode were actually exceedingly soft. Miners could gouge out the silver ore from the stope with nothing more than a sharp pick, which made extraction an easy but dangerous proposition. As the mine went deeper, the sheer weight of the rock above would crush conventional wooden timber props, and the entire mine was in danger of collapsing. The solution came from another European import, this time in the person of Philip Deidesheimer, a German graduate of the best mining school in the world, the Bergakademie (School of Mines) in Freiberg, Saxony. Deidesheimer developed a new "square set" timbering method that used heavy interlocking wooden beams to create a series of hollow cubes that could be extended indefinitely upward and to the sides. The process was somewhat analogous to constructing the skeleton of an immense wooden building—one that was thousands of feet tall and wide—entirely underground.[34]

Over the next two decades, Hearst's Ophir and the neighboring Comstock mines went deeper, some of them eventually reaching down to three thousand feet. To one contemporary visitor, the mines were like an underground industrial complex, a subterrestrial "city 3 miles long and half a mile wide." Others thought it resembled a huge series of interconnected tenement buildings, a sort of underground sweatshop for the mass extraction of silver ore.[35] Indeed, the reference to sweatshops was more than mere metaphor, as the air temperature in the mines increased by around three degrees with every hundred feet in depth. In the deeper zones, am-

bient temperatures reached 110 degrees Fahrenheit, while the groundwater percolating up from below was a scalding 170 degrees. The Comstock mine engineers improved ventilation by driving long horizontal adits from the side of the mountain into the mine workings, helping to encourage the passive circulation of air. Eventually, though, engineers had to install the largest pumps and blowers then available in the United States to transport surface air into the depths. Nonetheless, parts of the mines remained unbearably hot. Some companies lowered barrels of ice water into the mines. One Comstock miner wrote in his diary that work in the hot mines was still so arduous that it made him physically ill. Ironically, he was later killed when his sleeve caught in a ventilation blower that brought cool surface air down into the mine. Rather than having his arm cut off for quick transport to the surface for treatment, he chose to remain below in hopes of being extracted in one piece. He bled to death while he waited.[36]

The growing human cost of deep-level hard-rock mining would become even more evident in the highly engineered underground copper mines of Butte. Like the Comstock, Butte began as a placer gold mining camp before evolving into a gold and silver lode mining operation. Initial capital for the hard-rock lode mines came from local entrepreneurs like William Andrews Clark, a Montana merchant and banker who had shrewdly profited from earlier gold rushes in the territory. Recognizing the necessity of technical knowledge in successful hard-rock mining and smelting, Clark even traveled east to the new Columbia School of Mines in New York (an institution modeled on the famous Freiberg Bergakademie) for a semester of studies in 1872.[37]

Four years later, further technical expertise and the promise of big outside capital came to Butte with the arrival of Marcus Daly, a representative of two Salt Lake City smelter operators intrigued by the possibilities of Butte's silver ores. The son of impoverished Irish potato farmers, Daly immigrated to the United States in 1856 at the age of fifteen. He followed the mining frontier to California and eventually found his way to the Comstock Lode. Smart, gregarious, and affable, Daly rose quickly in the ranks of the Comstock miners, learning all he could about the technology of deep lode mining at the Comstock. Perhaps even more important for his future career, Daly won the trust and respect of George Hearst, the San Francisco capitalist who had made his fortune with the Ophir mine.[38]

Daly put his mining experience to good use in Butte, taking an option on a small but promising silver mine called the Anaconda that was a mere sixty feet deep at the time. He convinced his old Comstock friend, George

Hearst, to invest heavily in the mine, and Hearst brought in his partners, James Haggin and Lloyd Tevis. As the Anaconda went deeper, however, the signs grew that the mine contained more copper than silver. In late 1882, at a depth of about three hundred feet, Daly's miners hit an extraordinarily rich vein of the copper sulfide ore chalcocite. Daly asked Hearst and his partners to invest even more capital with the goal of creating a major copper mining and smelting operation on the isolated Montana mining frontier. According to the traditional story, Hearst and Tevis initially hesitated. Neither they nor Daly had any experience in copper mining, and it was not at all clear that a base metal like copper could be profitably mined so far from the nation's urban centers. Haggin, however, argued that Daly's judgment had always been keen in the past, and he convinced Hearst and Tevis to invest millions in the Anaconda operation.[39] A year later, the mine was six hundred feet deep and the rich copper vein was more than a hundred feet wide—one of the biggest copper deposits ever discovered.[40]

Where the Comstock had previously pioneered deep-level mining, the Anaconda now increasingly took the lead. Though he was not a formally trained mining engineer, Daly had learned a good deal about industrial mining through his apprenticeship on the Comstock. There he had the chance to inspect elaborate steam-powered water pumps, lifts, and ventilation systems. Unlike some western mine managers who had learned their trade on the job, Daly also valued the abilities of college-trained engineers, geologists, and other experts.[41] The contributions of the Freiberg-trained Phillip Deidesheimer to mining on the Comstock would not have escaped his attention. Perhaps his favorable impression of Deidesheimer later influenced his 1891 decision to hire August Christian as his chief engineer, another German native who had graduated from the Freiberg Bergakademie. Christian had overall authority over the engineering operations at the Anaconda mines until his death in 1914.[42]

Daly and his successors at the Anaconda also increasingly relied on the expertise of academically trained surveyors and geologists. Aside from rough sketches of developed mine works, elaborate underground maps were rare in the American West at the time. In a small mine with limited investment in hoists, pumps, ventilation systems, and mills, it might suffice for a mine manager to simply follow surface signs of ore down into the earth, coming to understand the shape and structure of the deposit only as the excavation of the shafts and tunnels slowly revealed it. For a deep and sprawling mine like Daly's Anaconda, though, it became increasingly important that the engineer and mine managers develop as much knowledge

as possible about the extent and nature of the deposit before mining began. Investors providing the big capital essential to developing the mine and mill wanted some reassurance that there was enough valuable ore to justify their investments. Absent good maps of the underground geology of Butte, managers like Daly had little choice but to do a great deal of initial "dead work"—shafts and tunnels that probed the size and richness of deposits but produced little profitable ore. Dead work was a costly means of envisioning subterranean space, but it was preferable to blindly following an ore seam into the ground where it might suddenly disappear.

Creating and efficiently managing deep mining operations demanded new ways of seeing and managing underground space. Daly had a reputation for being able to "see further into the ground than any other man."[43] But there were limits to what even a savvy and experienced mine manager could do without more advanced technical and scientific tools. Fortunately, for Daly and the other Anaconda managers who came after him, they were able to draw on the tools of another emerging profession, the mining geologist. As the geographer Steven Braun notes in his intriguing recent history of the development of "verticality" in Canada, by the end of the nineteenth century geologists, mining engineers, and governmental mining personnel had given "depth" to territories that had previously been seen in strictly terrestrial and (typically) agricultural terms.[44] In contrast to farmers, ranchers, or others with primarily agricultural interests, one of the striking aspects of the mining geologist's metric of visualization was the way it often ignored the traditional terrestrial human environment. Surface topography, rivers, vegetation, structures—many terrestrial features were ignored in order to better clarify the structure of the subterrestrial. In this narrowing of focus, of course, lay the visual power of the geological map. But it is also important to bear in mind how such maps helped to construct the subterrestrial environment as distinct from and unrelated to the terrestrial environment. Such a view would have its ultimate expression in Daniel Jackling's open-pit mine where the surface was literally stripped away, just as it had been symbolically stripped away in the mining geologist's map.

The great importance the Anaconda assigned to precise geological knowledge and mapping was ultimately reflected in the company's 1924 decision to combine the previously separate Geological Department with the Mining Engineering Department, both now under the direction of the "Chief Geologist and Engineer."[45] The increasing role of the geological sciences and mapping, however, should not obscure the continuing importance of the mining engineer's work in actually constructing the underground spaces necessary to exploit this knowledge. Mining engineers and managers not only adopted the geologist's construction of the underground world as an idea; they took on the challenging task of transforming that idea into an actual physical space, an environment in which humans could, however imperfectly, survive and work.

The Anaconda managers and engineers faced a multitude of challenges to carving out underground spaces, including the age-old problems of too much water and not enough air. The miners in Butte first began to intersect groundwater flows in 1877, discovering that the subterrestrial environment was home to vast lakes and rivers. The major groundwater bodies appeared at about 140 feet below the surface. Marcus Daly ordered two gigantic pumps from the Knowles Steam Pump Works of Warren, Massachusetts. Only a year earlier, the *Manufacturer and Builder*—a self-proclaimed "practical journal of industrial progress"—had praised the Knowles pump as "the most powerful and efficient steam pump ever offered in the American market." The big pumps were ideal for draining water in deep hard-rock mines, the journal suggested: "The Knowles Steam-Pump Works built pumps guaranteed to pump water from mines from 100 to 1,000 feet in depth," and the pumps could handle the gritty and corrosive water of mines without frequent repairs.[46]

Perhaps Daly read this very article when contemplating how to solve his flooding problems in the Anaconda, though he would likely have known about the famous Knowles pumps already. The pumps were expensive—Daly had to pay $100,000 for two of them, roughly the equivalent of at least $2 million today. To continue mining below the groundwater table, though, Daly had to have these sophisticated machines. Butte miners without the necessary capital or technical expertise to continually pump water up from the depths and out into the terrestrial environment had to either sell out or shut down. For the next century, mining in Butte essentially took place not only in an underground space, but in what had been an *underwater* space—one now kept dry only by the constant efforts of gigantic subsurface pumps.[47]

The pumps allowed Daly and other Butte miners to continue deeper into the earth, but this created new problems as well. As was the case at the Comstock, the Anaconda mines grew hotter with depth, and the heat and groundwater made for humid conditions. Bad or insufficient air was an old problem for miners, but the subsurface air quality problems at Butte and other mines were further aggravated in the late nineteenth century by

the replacement of human-powered hand drilling with steam-powered pneumatic rock drills. The rapid hammering action of the drills produced clouds of fine silica dust that lodged in the lungs of the miners. Many succumbed to silicosis as a result, a deadly lung disease all too common in Butte and many other western hard-rock mining towns.[48] In 1918, the Anaconda installed one of the most elaborate mining ventilation systems in the nation, using immense electric fans and miles of flexible canvas tubing to force surface air deep down into the shafts and through the mines. At the Mountain Con mine, which was over four thousand feet deep by the 1930s, mining engineers even built an elaborate evaporative cooling system in order to make a tolerable (though far from pleasant) environment for human labor.

The Butte mines also pioneered the use of technologies that permitted humans to survive and work in poisonous subterrestrial atmospheres. In 1853, a Belgian university professor developed a device to provide an artificial supply of oxygen for use by miners in noxious underground environments.[49] This "oxygen breathing apparatus" fed a fixed stream of oxygen from a pressurized tank to a head mask, while the wearer's exhaled breath (which still contained considerable oxygen) was recycled through a container of lye to absorb the carbon dioxide. Other devices based on similar principles followed during the next half century, exchanging technical improvements with the parallel development of deep-sea diving devices.[50] H. A. Fleuss developed and marketed a machine in London as early as 1880, and in 1903 Bernhard Draeger of Lübeck, Germany, began selling a popular device. Initially, all these breathing machines were able to provide only a limited supply of oxygen, and many of them were awkward, flimsily built affairs poorly suited to the rough treatment they had to face in a mine.[51] Still, for decades they offered the only means by which humans could enter into mines where the air was poisonous or lacked adequate oxygen.

The first subterrestrial breathing machine arrived in Butte in 1907. The Boston & Montana Smelting & Refining Company (a company later absorbed by the growing Anaconda combine) purchased five of the machines from the Draegerwerk in Lübeck. The Anaconda soon after bought several Draeger units as well.[52] The device used two steel cylinders charged with oxygen at 120 atmospheres, which was enough to last two hours in ideal conditions, though the ideal was rarely the case in practice. The oxygen from the tanks passed through rubber tubes to either a helmet tightly sealed around the face or a valve held directly in the mouth. The helmet model—an often unnecessary holdover from the deep-sea diving use of similar machines, and one that led the wearers to be dubbed "helmet men"—had a sponge wired inside to wipe away moisture that formed on the mica face shield. Condensation problems were avoided with the mouthpiece model, in which case the wearer's nose was held tightly shut with a clip. However, the helmet design did keep thick smoke and poison gases away from the eyes. As the more efficient mouth-fed devices gained in popularity, miners wore goggles rather than the bulky and constricting Draeger helmets.[53]

Within months of taking delivery of its first five Draeger machines, the Boston & Montana put them to use when a fire broke out in the company's Minnie Healy mine. Despite the deadly streams of dense smoke choking the subterrestrial mine passages, miners wearing the Draeger devices went down the shaft, made their way through the tunnels, and built several sturdy bulkheads to contain the fire. They returned to the surface unharmed, having saved the Boston & Montana thousands of dollars in damages and ore losses. A few months later, the U.S. Geological Survey (USGS) tested its new Draegers after a horrific explosion at the Monongah coal mine in West Virginia that took 356 lives. Donning a Draeger helmet, a USGS investigator was able to immediately descend straight to the explosion's center while the area was still devoid of oxygen. With the evidence fresh, he was better able to determine the cause of the explosion.[54]

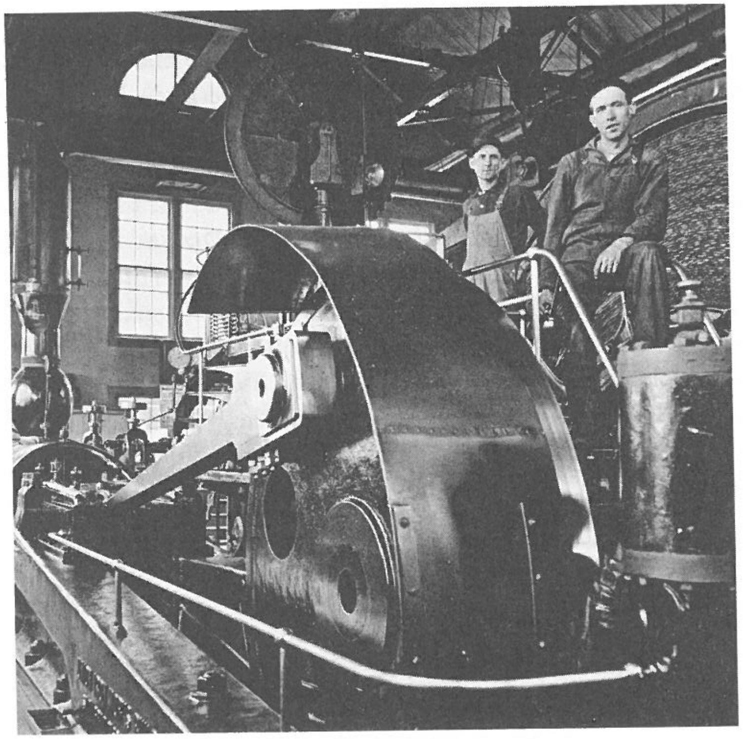
For the first time in the long human history of mining, miners could actually carry their own supply of air. Doing so was still dangerous, though, and miners needed careful training to properly operate the machines. Just as important, the miners had to learn to suppress the sense of panic and fear that often seized inexperienced users when they entered a potentially deadly mine. Miners were taught to trust the life-sustaining power of the machines they carried on their backs—even though that trust was not entirely warranted. A 1923 Bureau of Mines study found that twenty-seven "helmet men" had died that year while conducting rescues or doing other work in a toxic mine environment. This was a fatality rate of 1.2 percent. The report did not list the number of men who were seriously injured, but it must have been much larger.[55] Despite the risks, more than seventy thousand miners took the bureau training course between 1911 and 1940, and they undoubtedly helped to save the lives of many of their coworkers.[56]

Some companies also demanded that miners use the machine for considerably less noble reasons. Many took advantage of the technology to speed repairs in damaged mines, or even to resume mining in environments that would otherwise have been deadly. In 1911, a huge underground

fire at the Phelps Dodge Copper Queen mine in Arizona inundated some areas of the mine with highly corrosive sulfur dioxide smoke. At depths between a thousand and thirteen hundred feet, temperatures hovered around ninety-seven degrees with nearly 100 percent humidity. This sulfuric acid steam bath ate away at the mine hoist cables and the bolts that held the hoist cage together. To keep the hoist operating and the mine open while the fire burned, Phelps Dodge sent men wearing Draeger oxygen helmets into the shaft day and night to repair the machinery. In other cases, companies demanded that miners use the helmets merely so they could continue extracting ore in a toxic section of the mine.[57] In an earlier age, these mines would have been abandoned, but with breathing machines, miners could continue to work in such dangerous underground environments.

Mining engineers and managers at the Anaconda and other big copper mines thus repeatedly used technology to surpass the subterrestrial environmental barriers to human survival. With these technologies, engineers, managers, and miners created a wholly new type of human environment, one in which the seemingly solid categories of the "natural" and the "artificial" became confused and intermixed. Groundwater removed from the mines by steam pumps became part of natural surface water drainages. "Natural" surface air, artificially cooled and transported by giant fans and hoses, became part of the subterrestrial environment where miners breathed and worked. The miners themselves moved continually between terrestrial and subterrestrial worlds, their hybrid machine-dependent lives underground coming to seem as natural as their terrestrial lives under the sun. With Draeger machines, men could even survive for a few hours' time in subterrestrial atmospheres that would otherwise have quickly killed them.

It is difficult to find an earlier or more striking example of the emerging modern ability of human beings to create habitable environments in hostile natural circumstances. In many ways, these deep subterrestrial environments were the precursors to the modern engineered environments in jets and spacecrafts that sustain human life in equally hostile circumstances. However, the degree of the mining engineers' ability to create and control subterrestrial environments should not be overstated. Despite the engineers' best efforts, the mines remained challenging, complex, and dangerous places. Further, the engineers also continued to depend on the expert knowledge of the underground workers to carry out the actual mining. The miners' knowledge of the layout of the mine, their ability to judge the strength of the rock and whether it needed timbering, and their skill in using explosives with maximum effectiveness were all essential to



5. Operators pose proudly by one of the big steam-powered lift engines that made deep-level mining in Butte possible. With such powerful hydrocarbon-fueled machines, engineers were able to create hybrid technological and natural subterrestrial environments, early precursors to the life-support systems found in modern jets and spacecrafts. *Courtesy Montana Historical Society Photograph Archives, Helena.*

the efficient production of the mine. Control of the mine also did not lead to the elimination of mining accidents and industrial diseases like silicosis. To the contrary, the rationalization of the mine for increased speed and production could often create new safety hazards.[58] In decades to come, worker safety became an increasingly important goal for the Anaconda and other big mining companies, but the mines remained very dangerous environments for workers, as do hard-rock mining operations to this day.[59]

As many historians have pointed out, the continuing dangers of underground played a role in the formation of unions among the western miners. It was no coincidence that the technologically advanced mining city of

Butte was also an important early center of organized labor. For a time, Butte well deserved its nickname "the Gibraltar of unionism." The Butte Miners Union was one of the earliest and most powerful unions to form in the western hard-rock mining districts, and it played a major role in the later creation of the nationwide Western Federation of Miners. Thanks in part to union efforts, Butte's miners were among the highest-paid workers in the nation at the turn of the century.[60] The Butte unions weakened in the early twentieth century, however, from a combination of hostile management attacks and splits among the workers themselves. The technological rationalization of the subterrestrial environment that helped increase and maintain productivity also undermined the power of the miners, as knowledge and control increasingly shifted into the hands of the engineers and management.[61] As the Butte miners became more dependent on complex technologies—not only to do their work but also simply to stay alive—the relative independence they had once enjoyed underground diminished. Both as workers and as living and breathing biological organisms, the miners became ever more deeply enmeshed in and dependent upon Butte's vast subterrestrial envirotechnical system.

When these elaborate life-support systems failed in some minor way, as they often did, the consequences were not always serious. Water pumps, ventilation systems, hoists, and all the many other pieces of the machinery of underground life occasionally broke or malfunctioned. Managers would dispatch mechanics and engineers to repair the problem, and such breakdowns were mostly annoying inconveniences to the working miners. But when these complex systems failed disastrously, the consequences could be deadly. The worst hard-rock mining disaster in American history occurred at Butte's Speculator mine, a property owned by one of the few remaining operators not yet controlled by the Anaconda. On the night of June 8, 1917, workers were lowering an electrical cable twelve hundred feet long and five inches thick down the mine shaft. Weighing nearly three tons, the cable—made of a highly purified form of the very copper minerals that other miners were removing from the Speculator at that moment—was needed in order to complete installation of a new sprinkler system designed to prevent fires in the mine. While lowering the cable, though, the workers accidentally dropped it down the shaft and subsequently set fire to the oil-soaked insulation wrapped around the copper wire. The fire quickly spread up the length of the cable and then jumped to the wooden planks lining the shaft itself. Within minutes, the shaft had become "like a gigantic torch," as one horrified Butte resident later recalled.[62]

In the hours and days to come, the fire in the mine would eventually claim the lives of 164 men. Only a few died in the flames. Most were killed by the invisible and odorless carbon monoxide gas that stealthily spread throughout the underground tunnels. The gas killed some men before they even knew what had happened. Others died only after long desperate hours waiting in the darkness for rescue crews that came too late. Rescuers did manage to save many men who otherwise would have likely perished, thanks in large part to the breathing machines that allowed them to enter the still poisonous mine passages.[63]

In the weeks after the Speculator mine disaster, workers responded to the tragedy with strikes and the formation of a new union. Although the deaths of 164 men in the massive fire clearly played a role in reviving union interest, demands for improved safety and working conditions were secondary to calls for union recognition and better wages.[64] Indeed, by the standards of the day, the North Butte Mining Company that operated the Speculator was already widely viewed as one of the more safety-conscious companies in Butte.[65] For some miners, though, the catastrophic failure of the company's subterrestrial life-support and safety systems was symptomatic of much deeper failings in the entire system of industrial mining. As one of the union handbills distributed after the fire argued, the "terrific holocaust at the Speculator mine" had its root cause in management's insistent demands to maximize ore production and "GET THE ROCK IN THE BOX."[66] Anger over corporate failings to engineer a reasonably safe working environment could easily shade into more fundamental anger over the injustices of corporate capitalism itself. In the turbulent wake of the disaster, the staunchly anticapitalist International Workers of the World (IWW) gained some ground among the Butte miners. The Anaconda responded by importing two hundred hired "detectives" and spies to infiltrate and undermine all union efforts, radical or not. The Anaconda's "goon squads" may well have played a role in the grisly murder of IWW organizer Frank Little, though the historical record is equivocal on this point. The IWW organizer had more than a few enemies, and his killers might have been rival union men or hyperpatriotic Montanans angered by his vocal criticism of American involvement in World War I.[67] Either way, few tears were likely shed among the Anaconda managers upon hearing of Little's death.

Given this volatile mixture of death and murder, anger and retribution, unions and capitalism, it can be difficult to place the Speculator mine disaster in its broader context as an industrial accident. But whatever its

meaning as a symbol of corporate greed or the failings of capitalism, the Speculator fire must also be understood as a massive failure of a complex technological system. In retrospect, the fire appears to have been a case of what the organizational theorist Charles Perrow calls a "normal accident." Perrow argues that normal accidents inevitably occur in highly complex and tightly interconnected technological systems. Within such systems, even relatively small failures can cause an unforeseen chain of effects that lead to disaster. Even efforts to engineer in safety and fail-safe measures can inadvertently contribute to a catastrophic system failure. Since engineers and designers cannot possibly predict the course of these highly dynamic failures, Perrow argues, accidents will be an unavoidable, if rare, consequence of the normal everyday operation of such systems.[68]

In this sense, the Speculator disaster appears to have been at least in part a consequence of the growing complexity of the subterrestrial envirotechnical system. As Perrow's theory suggests, even the engineering efforts to increase the safety of the mine contributed to the tragedy. As already noted, the men were lowering the electrical cable that day as part of a project to install fire-suppression sprinklers in the shaft. The cable fed electricity to a transformer, which in turn provided power for electric lights and other devices that significantly improved mine working conditions (though they also created the new danger of electrical shocks). The oil-soaked cable insulation that caught fire was also a safety measure, a means of protecting workers from electrical shocks in the era before plastic insulation. That the small fire had spread so quickly and made the shaft into a "gigantic torch" was partially the unintended consequence of engineering efforts to improve the underground atmosphere. The Speculator had a reputation for being one of the best-ventilated mines in Butte thanks to the brisk circulation of air down one shaft, though the mine tunnels, and out a second shaft. The night of the disaster, this ventilation system that normally brought vital air to workers both fanned the burning flames and carried the resulting smoke and carbon monoxide deep into the most distant mine passages. Tragically, an envirotechnical system designed to bring cool fresh air to the miners now brought them carbon monoxide and death.[69]

Of course, none of this is to suggest that the managers and engineers of the Speculator could not have done more to make the mine safe. They certainly could have, and subsequent investigations suggested at least some level of company negligence as well as abundant evidence of missed opportunities to improve safety. At another level, though, the Speculator mine disaster was a product of the growing complexity and interconnectedness of early twentieth-century underground mining. Engineering and managing deep subterrestrial environments like those at Butte were becoming more complex and difficult, particularly in terms of the environmental support systems that kept workers alive at ever more dangerous depths. Problems that might have been easily dealt with in a two-hundred-foot-deep mine, or perhaps would have never occurred at all, had far graver consequences in a three-thousand-foot-deep mine—especially for the vulnerable human beings whose survival depended on machines. Thus, just as hydraulic mining and open-pit mining shifted some of the costs of efficient development to the natural world, so too did deep underground mining shift some of the costs to the humans who worked there. Even technologies designed to sustain subterranean human biology could at times prove deadly.

For more than two thousand years, the human drive to push ever deeper into the earth in pursuit of minerals has created growing challenges and dangers. The Romans, careless of the lives of slave workers, used only the most basic technologies in their mines of Rio Tinto, creating subterrestrial hells a thousand feet below the surface. Saxon miners of medieval Germany reached similar depths but created somewhat more humane working environments with ingenious water-powered pumps and fans. The British and later the Americans used steam engines and the concentrated energy of coal to increase their power to dewater and ventilate mines, making it possible for an industrialized workforce to labor in the extreme heat and humidity two-thousand feet down in mines like the Comstock Lode. Coal, and later oil and hydropower, sustained human life and work at four thousand feet beneath the city of Butte by the 1930s, providing the essential energy to drive immense evaporative air conditioners and fans on the surface. Thirty years later, the engineers of Anaconda's Mountain Con mine used similar technologies to push more than a mile below the surface and earn the city its motto: A mile high, a mile deep.

The engineering of these immense subterranean human worlds was one of the greatest technological achievements of the modern age. However, the hidden mines of Butte have never earned the mixture of attention, admiration, and criticism lavished on more obvious terrestrial icons of modernity like the Empire State Building, the Panama Canal, or Hoover Dam. Imagine, though, if the mines of Butte were somehow carved out of the surrounding rock as a single block, lifted up, inverted, and set back

down on the surface. The resulting structure of stone, steel, and wood would, in many regards, far surpass any other on the planet. A mile high at its tallest point, the Butte mines would be twice as big as the world's largest skyscrapers, while the 726-foot-high Hoover Dam would be dwarfed in comparison. Nearly two miles thick at the base, the mines could easily contain dozens of Pentagon-sized buildings within just their lowest levels. Likewise, the Pentagon's much ballyhooed 17.5 miles of corridors are minuscule in comparison to the mines' 10,000 miles of vertical and horizontal passages. Of course, a roughly cut mine passage is hardly the same thing as a Pentagon hallway or a corner office on the ninety-first floor of the Empire State Building. On the other hand, though, the engineers of those structures did not have to provide for the constant removal of water or deal with ambient air temperatures over one hundred degrees Fahrenheit.

The point of such comparisons is not to minimize these other engineering accomplishments so much as to highlight how the extraordinary achievements of modern mining engineering have often been overlooked—in part, simply because their creations are hidden underground. The oversight is all the more unjustified when the mines are seen in their proper light as early examples of highly sophisticated environmental engineering. In what other environment had engineers achieved an equally clear expression of the high modernist drive to rationalize, simplify, and control nature? In the mine, the factory was embodied in nature, the natural and technological surrounded and enmeshed the human, and the human worked in a hybrid world where technology and nature were inextricably fused. In *Seeing Like a State*, James Scott offers the rationally planned German forests of the nineteenth century and the futuristic cities of Le Corbusier as prime examples of the material expression of high modernist faith. However, the twentieth-century underground mine—man-made like the modernist city, but also a part of nature like the German forests—suggests an even more compelling and revealing example.[70]

Until the post–World War II construction of semipermanent human dwellings beneath the sea and in space, the members of no other profession succeeded so well as mining engineers in creating new environments in which humans could live and work. In this sense, these mining engineers were among the world's first environmental engineers. The subterranean mine is best understood as a hybrid system that combined natural and technological systems, rather than as a completely artificial construct imposed on a natural world. Engineers worked with natural environmental systems just as much as they tried to dominate and overcome them.

Success required learning about the nature of subterrestrial water systems and airflows just as much as it required learning about the operation of Knowles water pumps and Draeger helmets. Above all else, mining engineers had to provide for the basic natural biological needs of human bodies doing hard labor.

Recognizing that mining engineers were successful subterrestrial environmental engineers also helps us to understand why many believed they could also engineer terrestrial environments. When confronted with the problem of terrestrial smoke pollution from smelters that processed the ore from their subterrestrial mines, the engineers faced the challenge with the confidence that they had the tools to solve the problem. Surely it was not too much to believe that there were terrestrial analogues to the giant Knowles pump that could "drain" the atmosphere of pollutants, or ventilation systems that could sweep smoke from the valley? Contrary to the views of some, these mining engineers and entrepreneurs were not necessarily ruthless and reckless natural despoilers who cared for nothing but profits and power. To be sure, some were concerned mostly with their own bank accounts and careers, and others had few qualms about destroying a relatively small area of the planet in the name of what they believed was material progress. However, many of these men also deeply admired the natural world and wilderness, and there can be little doubt that they made sincere efforts to minimize the pollution and environmental degradation of mining.

For these engineers, their failures often stemmed not from a careless disregard for environmental problems but rather from a dangerous overconfidence in their abilities to fix these problems. In an era when an uncritical faith in technological progress had yet to be seriously challenged, they believed that the modern ideas and methods that had served them in building mining complexes thousands of feet below the earth would also allow them to solve pollution problems on the surface. However, the mining engineers would have done well to heed the lessons of subterrestrial disasters like the Speculator fire, or of the thousands of other failings, big and small, that constantly plagued their elaborate mining systems. For all their accomplishments, their control of the underground world they had created fell well short of perfection, most tragically when it came to the systems that kept the human miners safe and alive. Their attempts to engineer the far more complex biological and ecological systems on the surface would soon prove equally flawed.

ENGINEERS IN THE WILDERNESS

When Rossiter Raymond, one of the nation's most prominent early mining engineers, first visited Colorado, he thought it "the most beautiful territory" he had ever seen, praising its "great grassy plains, with their herds of peaceful cattle, the grand mountains, the clear-flowing streams."[71] Some years later, in 1887, while returning to Salt Lake City after a hard day's work examining a mine, Raymond was struck by the sight of the Wasatch Range rising from a sea of snow: "On our side [were] orange clouds where the sun had set, the sky a delicate apple-green, an exquisite rose-tinted Abendroth on the upper half of the Wasatch Peaks, and over them in the green sky a silver, strictly silver, moon!"[72]

Reading Raymond's words today, one might assume they were penned by some late nineteenth-century nature writer. But despite his purple rhetoric, Rossiter Raymond was anything but a simple nature worshipper. Raymond, like most other mining engineers of the late nineteenth and early twentieth centuries, held a complex and sometimes contradictory view of the natural world. Many mining engineers shared Raymond's deep affection for nature and wilderness, which they believed were essential to both national character and the health of an overly civilized people. At the same time, though, engineers believed that their own identity as professionals and as men emerged from their aggressive conquest and mastery of nature. Thus, the mining engineers faced a dilemma: the more they succeeded in taming nature, the more they denied themselves the rugged wild places essential to the creation of their personal and professional ideals.

In the modern mind, the stereotypical engineer is obsessively rational and abstract, uncomfortable with emotions and concepts like aesthetic natural beauty that resist precise measurement. Spock, the Vulcan chief scientist in the 1960s American television show *Star Trek*, was an intriguing popular expression of this modern concept of the engineer. Though he was half human, Spock generally seemed incapable of emotion. Instead, he relied entirely on logic to understand the world, and his hyper-rationalism typically served the starship *Enterprise* well. Indeed, to the modern mind a spaceship itself seemed the ideal environment for this ideal engineer. The *Enterprise* appeared to be a wholly artificial environment, a world entirely cut off from nature and dependent on technological rather than natural life support systems. The program suggested the perfect environment for the engineer was one in which humans had essentially eliminated nature and replaced it with technology. The ecosphere had become the technosphere.

The mining engineers of the second half of the nineteenth century would have found such concepts bizarre. To them, engineering was still a humanistic profession, and the idea that an engineer should be devoid of emotion or aesthetic passions would have been foreign. Nor would they have been nearly so likely to believe—or desire—that the technological could or should be separated from the natural. Rather, the two concepts still remained closely entwined in their imaginations. As the prominent mining engineer T. A. Rickard once wrote in describing the work of the mining engineer, "The operations of nature, mechanical and chemical, are supplemented by those of man, who is a great mimic."[73] The engineers were far from alone in this. Scholars have pointed out that even the early science of ecology, which was developing at roughly this time, focused on understanding natural environments in order to improve human exploitation of them. The equation of ecology with an environmentalist ethic of preservation only began much later.[74]

For Raymond and many other mining engineers, nature was simultaneously a place to be admired for its natural beauty and the ideal venue for developing and demonstrating their professional ideals of physical strength, courage, and masculinity. This belief that the professional mining engineer should be the epitome of nineteenth-century masculinity is most readily evident in the training students received in the many new western mining schools founded during the late nineteenth and early twentieth centuries. At the Colorado School of Mines in Golden, for example, one of the first bits of school trivia memorized by the freshman mining engineer each September—just in time for football season—was the boisterous school fight song:

> Now here we have the mining man
> In either hand a gun;
> He's not afraid of anything,
> He's never known to run;
> He dearly loves his whisky,
> He dearly loves his beer;
> He's a shooting, fightin',
> Dynamitin', mining engineer.[75]

The song, of course, was supposed to be hyperbolic—it was a "fight song," after all. Yet it is also a reflection of how the student culture at Golden

repeatedly drove home the idea that the mining engineer was a "true" man—virile, strong, unstoppable, and sometimes aggressive to the point of violence. Even the student dress code imposed by seniors marked the passage into engineering manhood. An article in the student newspaper warned the new student about wearing headgear inappropriate to his lowly status: "See the boy with a Stetson hat. He is not a boy, he is a Senior, and that is why he is a man, and that is why he wears a Stetson."[76]

At the Colorado School of Mines, the students equated manliness with the status of the professional mining engineer, and the chosen symbol of both was that icon of western expansion and exploitation, the Stetson cowboy hat. At times, the message went beyond symbolic expressions and clearly embraced the idea that engineers were the masculine tamers of a wild frontier. In a student newspaper editorial about a class inspection trip to some western mines, the writer celebrated the joys of hitting "the trail for the land of romance, where mines become living realities." The students, he suggests, were heading "out where the West begins, and with it, life in the great open spaces. The freedom of the West, not the movie paradise of Tom Mix, but the virile country that produced the entrepreneurs of the past decade, [and] the days when the white man took charge, exterminated the bison and broke the spirit of the Indian. The time when settlers molded camps and made a living while Mother Nature looked on and smiled." With a clear sense of nostalgia for paradise lost, the editorialist concludes, "Those were the days when men were men and romance captured the world."[77]

The Golden student culture reflected broader trends in the American culture of the day. Historians have discovered compelling evidence that many Americans were reacting against a supposed "feminization" of the nation in the decades around the turn of the century. Journalists, writers, politicians, and others claimed that Americans had become soft and effeminate during the Victorian age. Changing gender roles and the erosion of the male-dominated Victorian society of the past made many American men uncertain of their own masculinity. Some embraced various forms of what Theodore Roosevelt called the "Vigorous Life" as a remedy. Roosevelt and others urged American men to rediscover their physical and moral strength by visiting the "uncivilized" remnants of the natural world. Inspired by this "back-to-nature" movement, many men came to view the American West in particular as the ideal battlefield for recapturing their masculine identity.[78]

In the eyes of most Americans, science and technology also had a gender.

Many considered math and physics to be the "hard," masculine sciences, whereas geology, the life sciences, and other less immediately practical pursuits were "soft," or feminine. Professional engineers and geologists were new to the western states and their worth not yet fully proven in the late nineteenth century. In comparison to the mine operators and timber barons who repeatedly demonstrated their value by producing wealth and essential natural resources, the geologists and their pursuit of scientific and aesthetic interests in nature at first appeared to be economically marginal. As a result, geologists often took pains to camouflage their "feminine" affection for nature while emphasizing their "masculine" usefulness in the national drive to exploit natural resources.[79] In the same way, practically trained mine operators sometimes looked askance at college-trained engineers, with their abstract theories and emphasis on science. At the very least, the mining engineers' "feminine" appreciation for nature had to be balanced and legitimated by their useful economic role in exploiting nature.

Students at the Colorado School of Mines and other mining schools were thus immersed into a culture that tied their status as men and as professionals with the aggressive economic exploitation of a feminine natural world. Not surprisingly, such a view of nature easily translated into a deep discomfort with the idea of female mining engineers. From its inception in 1874, the Colorado School of Mines had theoretically been open to women, though it is unlikely the school administrators encouraged women to enter. In general, many engineering school administrators believed that training women was a waste of time since they were likely to marry and never put their education to use. Still, at Colorado the school would admit women if they could demonstrate their commitment to the program and were fully aware of and accepted "the conditions established in the school and on the campus." Either few women applied or few applicants met these conditions. In the eighty years from the school's founding to 1955, only four women graduated from the institution. Confounding assumptions, all four went on to pursue long and successful careers in engineering. Three of them eventually married and had children yet carried on with their careers.[80]

Four successful women graduates, though, were hardly enough to dissuade the Colorado administrators and students from the belief that theirs was a profession suited only to men. To the contrary, the students at Golden believed they were training for a special type of profession that required as much brawn as brains. They hoped this physical side of mining

engineering would limit what they saw as the insidious encroachment of female students into other engineering professions. In 1927, one editorialist notes how strange women would seem within the manly culture of the mining school: "Naturally, because of our years of freedom from the gentling influences of women, Miners are rough, tough, and uncouth savages ranging the wilds of the Front Range of the Rockies." Women, he argues, would surely be uncomfortable among the hard-edged men of mines.[81] In a 1926 editorial, the author recognizes that women had begun to enter into the business world and had demonstrated their worth. Soon they would be an influence in many engineering professions, where, he admits, they had shown some aptitude for office work and laboratory research. With a nearly palpable sigh of relief, though, he concludes that because of the physical challenges of fieldwork, "mining is about the only branch of engineering that can be kept free from their influence."[82]

The school culture at Colorado thus closely linked the profession's relationship to nature and its relationship to women. In this view, the job of the mining engineer was sometimes physically taxing and required vigorous battle with an often dangerous natural world. The supposedly weaker and more timid sex was, therefore, unsuited to the profession. The mining engineer's triumph over nature highlighted his masculinity and paralleled the supposed rational and physical superiority of the male gender. This idea was far from unique to the mining engineers, and many scholars have discovered that similar ideologies pervaded the wider development of western science and technology. Mary Midgley, for example, reveals the highly gendered language of seventeenth-century scientists who spoke of mastering a female natural world.[83] Likewise, David Noble argues that modern science and technology are deeply rooted in medieval Christian monasticism. As these monastic "worlds without women" played a key role in the early development of Western science and technology, this gender division persisted, ensuring that women were widely perceived as technically and scientifically inept.[84]

Given such a historical heritage, it comes as no surprise that the emerging engineering professions of the nineteenth and early twentieth century equated masculinity and technological mastery. The tie was especially close within the more "practical" engineering professions, such as the mining engineers. As the historian Judy Wajcman argues, "All the things that are associated with manual labor and machinery—dirt, noise, danger—are suffused with masculine qualities. Machine-related skills and physical strength are fundamental measures of masculine status and self-esteem according to this model of hegemonic masculinity."[85] Likewise, Sally Hacker argues that the engineering professions emphasized scientific abstraction and technical competence and dismissed the value of human traits culturally associated with femininity such as nurturance and sensuality. The engineering professions justified their exclusion of women because women supposedly lacked both physical strength and the ability to think abstractly and rationally.[86]

The ways in which mining engineers looked at women and gender were symptomatic of the broader cultural shift toward constructing a conceptual barrier between the technological and the ecological. As technological systems became increasingly powerful and seemingly dominant, men claimed them as their unique province. Supposedly, only they had the requisite rational and analytical abilities to create and manage these complex modern technological systems. By contrast, women were increasingly associated with natural ecological systems, supposedly simple and holistic worlds suitable to their more nurturing but less incisive minds. It was, perhaps, not coincidental that Americans also began to embrace the ideal of wilderness during this time. Just as ecological woman was set apart from technological man, so too was the wilderness increasingly defined by its separation from the technological. Again, the ecosphere became distinct from the technosphere, the lower realm of the earth from the higher realm of the heavens, the wildness of nature from the rationality of the spaceship. Likewise, just as men used the power dynamics of gender to dominate women, so too did they increasingly believe their technological systems could dominate or marginalize the natural world—or perhaps even subsume nature altogether.

Historians have found evidence that this radical modern dichotomization of the human and the natural was taking place in other areas at roughly the same time. In their insightful examinations of the creation of the American national parks, Mark Spence and Louis Warren demonstrate how the new idea of "wilderness" required that humans and their artifacts be removed from places like Yellowstone and Glacier. Most tragic, even Native Americans who had long made use of these areas for spiritual and material purposes were cast out of what Americans increasingly wished to view and re-create as pristine Edens.[87] Karl Jacoby suggests a similar banishment affected many Americans who lived near parks and forest reserves and used them for subsistence hunting, wood gathering, and other productive purposes.[88] Though these authors do not cast their analysis primarily in terms of technology, it is clear that wilderness areas like the

national parks were being defined in terms of the absence not so much of humans per se but rather of human technological activity for extracting natural resources.

Recent work by historians of the environment and medicine suggests a similar shift was taking place during this same period within American ideas about the human body. Conevery Valencius finds evidence that many nineteenth-century Americans believed that the health of their bodies was closely tied to the "health of the country," suggesting the continued existence of a holistic view of nature and the human place within it.[89] Likewise, Linda Nash argues that even as late as the early twentieth century, doctors in California still saw human health as a product of complex interactions between the human body and nature. At the same time, however, such holistic views that tied the human and natural together were being challenged by modern reductionist concepts of human health. As Nash explains, in this emerging new scientific view, the human body was increasingly seen as largely separated from nature. Diseases were thus caused not by a complex web of interactions between body and environment but rather by specific germs or other pathogens that managed to invade the barrier separating the human and natural worlds. A more holistic and ecological view of human health, Nash concludes, would not reappear until the post–World War II resurgence of environmental sciences sparked by Rachel Carson's analysis of pesticides in natural food chains.[90]

As professionals whose work was deeply embedded in natural and biological systems, mining engineers were struggling with precisely this same modern tendency to divide the human and the natural, the technological and ecological. Much like Nash's doctors, they initially believed that humans and technology were part of natural systems and that they could manage the combination. Nature and technology could be effectively integrated. However, as the challenges of engineering the environmental and technological interactions in the places like the Deer Lodge Valley became more complex, engineers and their corporate masters would increasingly reject such holistic concepts and embrace the modern dichotomous view that split the technological from the environmental, the human from the wilderness, and even the male from the female.

Such modernist dichotomies served a vital purpose, both facilitating and justifying the domination of a distinctly separate nature, just as they facilitated and justified the broader male domination of women in American society. What we believe is separate and distinct from us, we believe we can safely exploit, control, or marginalize. In time, the engineers would discover that these divisions were illusions as their attempts to simplify and control complex environments and technologies began to fail and ultimately collapse.

In 1911, Thomas Edison was the guest of honor at a luncheon held for the opening of an "Electrical Exposition" in New York City. According to a *New York Times* story on the gathering, many other "notables in the electrical world" attended, including Edison's longtime rival George Westinghouse. The highlight of the expo was a six-room house that had been "fitted out with everything that has been invented to make electricity do the work," from "milady's curling irons in the boudoir to a dish-washing machine in the kitchen." All the electric lights and devices were symbolically and literally linked back to Edison: the inventor had turned on the power to the expo the previous day via a remote switch wired to his lab in New Jersey.

During the luncheon, a group of "producers and consumers" of copper took advantage of the occasion to present Edison with a gift. During an earlier dinner with the inventor that year, these "copper men" had "lauded Mr. Edison, and rejoiced in the vast increase in the output due to him." Ever the good businessman, Edison had responded that it was a shame he had not had a "chunk of it." Eager to express their "appreciation of the part his inventions have played in the continuous stimulation of the copper industry," the copper men came up with what they considered the ideal symbolic gift: a solid cube of pure copper one foot on each side. Weighing 486 pounds, the copper cube was supposed to represent a "chunk" of the increased business the copper men had enjoyed over the past forty years. Inscribed on one face were the statistics for the American output of copper in 1868—the year of Edison's first patent—and for 1910. Output was just under 378 million pounds in 1868 but had grown to 1.9 billion pounds by 1910, a fivefold increase. Fittingly, one of the "copper men" present that day was Charles Kirchhoff, the president of the American Institute of Mining Engineers.[91]

After examining his heavy gift, Edison joked, "It might make a good paperweight." There is no evidence that the sixty-four-year-old inventor gave the big chunk of copper much more thought than that, though he kept the cube on display in his West Orange lab for many years to come.[92] Still, one wonders if he ever paused for a moment during his visits to the lab to study the shiny mass of copper and consider its significance as something more

than a very heavy paperweight. He could not have known then about the giant stellar furnaces and supernova explosions that created and dispersed the copper he used in his electrical power systems. The scientific insights that would connect his bright little light bulbs to the lives and deaths of stars were still decades in the future. Given his lifelong interest in mining and metallurgy, he might well have understood something of the role hydrothermal deposition had played in concentrating the Earth's modest allotment of copper to a point that humans could discover and mine it. The theory of plate tectonics, however, was still unknown. A glance at the statistics engraved on the cube might have reminded him of one thing he likely already knew: that he owed as much to the leaders of the copper mining and manufacturing industries as they did to him. The fivefold increase in production made possible by Marcus Daly, Daniel Jackling, and others had provided the masses of cheap copper necessary to fulfill his vision of an electrified nation.

Perhaps it would be expecting too much to wonder if Edison also saw some of the costs paid in creating the 486 pounds of copper in his cube. Would he have even thought to see some pale reflection of Nick Bielenberg's dead cattle in its shiny red surface? Or later, after the Speculator mine disaster had been front-page news across the nation, of the 164 Butte miners killed in one of the safest and most technologically advanced underground mines in America? If Edison did consider such dark thoughts, they were likely fleeting. Like the engineers who had created those copper smelters and mines, Edison had an unshakeable faith in the power of science, technology, and invention to solve all such problems. It was only a matter of dedicating the necessary time, will, and effort.[93]

Though somewhat naïve in retrospect, such optimism was not altogether unwarranted. The electrical power system that Edison had pioneered would play a starring role in the success of one of the greatest technological fixes of the twentieth century: a machine that could actually capture smoke. But just as attempts to engineer a cleaner and safer subterrestrial environment in Butte contributed in unexpected ways to the Speculator disaster, so too would efforts to solve the smoke pollution problem in the terrestrial environment of the Deer Lodge Valley produce other unforeseen consequences. In time, the human dead zones below would find haunting echoes in the natural dead zones above.

10. "Henry Ford Is Dead at 83 in Dearborn," *New York Times*, 8 April 1947.

11. *Utah History Encyclopedia*, s.v. "Daniel Cowan Jackling."

12. In this emphasis on speed and nonselectivity, the concept of mass destruction is very different than the idea of "brute force technology" offered in Paul R. Josephson, *Industrialized Nature: Brute Force Technology and the Transformation of the Natural World* (Washington, D.C.: Island Press/Shearwater Books, 2002).

13. William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: Norton, 1991), 256–257.

14. This point is well made in Bruno Latour, *We Have Never Been Modern* (Cambridge: Harvard University Press, 1993), 10–11.

15. William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," *Environmental History* 1 (1996): 7–28.

16. "Ancient Lead Emissions Polluted Arctic," *Science News*, 5 November 1994.

17. Duncan Adams, "Did Toxic Stew Cook the Goose?" *High Country News*, 11 December 1995; and Mark Levine, "As the Snake Did Away with the Geese," *Outside* (September 1996).

18. Edwin Dobb, "Pennies from Hell: In Montana, the Bill for America's Copper Comes Due," *Harper's* (October 1996): 42–53.

19. Levine, "As the Snake Did Away with the Geese."

20. Jeffrey St. Clair, "Something About Butte," *Counterpunch* (January 2003).

21. This powerful Montana and later international mining company has gone through several corporate forms and names, including a period as a part of the Standard Oil trust when it was the Amalgamated Copper Company. For the sake of convenience and brevity, in this book the corporation will be referred to simply as the Anaconda.

22. Mumford's fascination with the Deutsches Museum mines is related in Rosalind Williams, *Notes on the Underground: An Essay on Technology, Society, and the Imagination* (Cambridge: MIT Press, 1990), 4–5.

23. Lewis Mumford, *Technics and Civilization* (1934; New York: Harcourt Brace, 1963), 65–77, quote from 69–70.

24. Williams, *Notes on the Underground*, 7–8.

25. Richard White, "From Wilderness to Hybrid Landscapes: The Cultural Turn in Environmental History (American West Portrayals)," *Historian* 66, no. 3 (2004): 560.

26. See, for example, T. C. Onstott et al., "The Deep Gold Mines of South Africa: Windows into the Subsurface Biosphere," *Proceedings of the SPIE* 3111 (1997): 344–357.

27. Edmund Russell, for example, has suggested the provocative thesis that stock animals, dogs, and perhaps other organisms can be usefully analyzed as human-designed technologies, which inspired a conference on this theme held at the Hagley Museum and Library. See Susan R. Schrepfer and Philip Scranton, eds., *Industrializing Organisms: Introducing Evolutionary History* (New York: Routledge, 2004). See also Michael Bess, "Artificialization and Its Discontents," and

Angela Gugliotta, "Environmental History and the Category of the Natural," both in *Environmental History* 10 (January 2005). Also seminal have been Arthur F. McEvoy, "Working Environments: An Ecological Approach to Industrial Health and Safety," *Technology and Culture* 36 (Supplement, 1995): S145–172; Christopher Sellers, "Body, Place and the State: The Makings of An 'Environmentalist' Imaginary in the Post–World War II U.S.," *Radical History Review* 74 (1999): 31–64; Conevery Bolton Valencius, *The Health of the Country: How American Settlers Understood Themselves and Their Land* (New York: Basic Books, 2002); Gregg Mitman, "In Search of Health: Landscape and Disease in American Environmental History," *Environmental History* 10 (2005): 184–210; and Linda Nash, "Finishing Nature: Harmonizing Bodies and Environments in Late-Nineteenth-Century California," *Environmental History* 8 (2003): 25–52.

From a history of science perspective, Bruno Latour's concept of a web of interconnected actors in which nature, humans, machines, maps, etc., are all linked avoids simple dichotomies of the natural and the artificial. See Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (New Haven: Yale University Press, 1988), and idem, *We Have Never Been Modern* (Cambridge: Harvard University Press, 1993). Examples of related (though far from identical) arguments emerged among environmental historians like William Cronon with his now classic article, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," *Environmental History* 1 (1996): 7–28; Richard White, *The Organic Machine: The Remaking of the Columbia River* (New York: Hill and Wang, 1996); and Mark Fiege, *Irrigated Eden* (Seattle: University of Washington Press, 1999). A pathbreaking early work was Donna Haraway's "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," reprinted in *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York; Routledge, 1991), 149–181.

28. See Tim LeCain, "The SHOT/HSS Roundtable on Envirotech Themes," *Envirotech Newsletter* 5, no. 2 (Fall 2005), 1–3, available online at http://www.stanford.edu/~jhowe/Envirotech/newsletters.html#Archived%20Newsletters, accessed 7 June 2007. Others on the panel—which in addition to Russell included John Staudenmaier, Martin Reuss, and moderator/organizer Hugh Gorman—made similar points about the convergence of technological and environmental systems.

29. Cronon, *Nature's Metropolis*, xix.

TWO. BETWEEN THE HEAVENS AND THE EARTH

1. Donald MacMillan, "A History of the Struggle to Abate Air Pollution from Copper Smelters of the Far West, 1885–1933" (Ph.D. diss., University of Montana, 1973), 111.

2. Robert Friedel, "New Light on Edison's Light," *American Heritage of Invention and Technology* (Summer 1985): 22–27.

3. Thomas P. Hughes, "Edison's Method," in *Technology at the Turning Point*, ed. W. B. Pickett (San Francisco: San Francisco Press, 1977), 9.

4. Association of Edison Illuminating Companies, Committee on St. Louis Exposition, *"Edisonia"* (New York, 1904), 49–50.

5. Ibid.

6. Frank Lewis Dyer and Thomas Commerford Martin, *Edison, His Life and Inventions* (New York and London: Harper & Brothers, 1910), 626.

7. On American electrification, see Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983), 18–46; David E. Nye, *Electrifying America : Social Meanings of a New Technology*, 1880–1940 (Cambridge: MIT Press, 1990); idem, "Electrifying the West, 1880–1940," *European Contributions to American Studies* 16 (1989): 183–202; Warren D. Devine Jr., "From Shafts to Wires: Historical Perspectives on Electrification," *Journal of Economic History* 43 (1983): 347–372; Richard F. Hirsh, *Technology and Transformation in the American Electric Utility Industry* (Cambridge: Cambridge University Press, 1989); and Harold I. Sharlin, *The Making of the Electrical Age: From the Telegraph to Automation* (London: Abelard-Schuman, 1963).

8. Harold I. Sharlin, "Electrical Generation and Transmission," in *Technology in Western Civilization*, ed. Melvin Kranzberg and Carroll W. Pursell (New York: Oxford University Press, 1967), 579.

9. Watson Davis, *The Story of Copper* (New York: Century, 1924), 257.

10. Bureau of Mines, *1952 Materials Survey: Copper* (Washington, D.C.: National Security Resources Board, 1952), S-1.

11. D. C. Jackling, "Copper—The Everlasting Metal," *Mines Magazine* 27 (November 1937): 15.

12. Davis, *Story of Copper*, xii.

13. Lewis Mumford, *Technics and Civilization* (1934; New York: Harcourt Brace, 1963), 70, 221–224, 229–230, 255.

14. David E. Nye, *American Technological Sublime* (Cambridge: MIT Press, 1994).

15. Charles Henry Janin, "The Copper Situation," a paper presented to the Commonwealth Club of California, 26 June 1924, Charles H. Janin Collection, folder 13, box 15, Huntington Library, San Marino, California.

16. Thomas A. Rickard, *Interviews with Mining Engineers* (San Francisco: Mining and Scientific Press, 1922), 215; "Bear Lake Reservoir and Lifton Pumping Plant of the Utah Power and Light Company," D. C. Jackling Collection, box 3, Bancroft Library; John S. McCormick, "The Beginning of Modern Electric Power Service in Utah, 1912–22," *Utah Historical Quarterly* 56 (1988): 4–22.

17. Carrie Johnson, "Electrical Power, Copper, and John D. Ryan," *Montana: The Magazine of Western History* 38 (1988): 24–37.

18. "Overland by Electric Cars Near Reality: Men Behind Biggest Power Supplying Corporations in West Also Control Mines That Supply Copper Required for Electrification," *Salt Lake City Tribune*, 19 January 1912.

19. A. B. Parsons, *The Porphyry Coppers in 1956* (New York: American Institute of Mining, Metallurgical, and Petroleum Engineers, 1957), 27.

20. Davis, *Story of Copper*, 246; Christopher J. Schmitz, "The Changing Structure of the World Copper Market, 1870–1939," *Journal of European Economic History* 26 (1997): 296–297 and n. 4.

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THREE. THE STACK

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