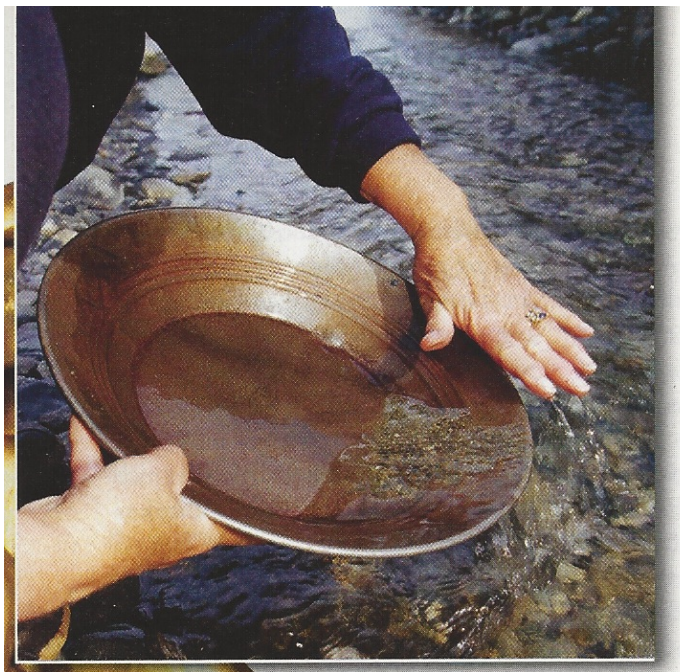


Gold

From Panning to High-Tech Mining

by Tom Farley

CARPENTER AND WHEELWRIGHT JAMES WILSON MARSHALL was just trying to build a sawmill on a California river, not to start a gold rush. But what he found in the tailrace on January 24, 1848, forever changed both California and America itself: "My eye was caught by something shining at the bottom of the ditch. . . . I reached my hand down and picked it up; it made my heart thump, for I was certain it was gold. The piece was about half the size and shape of a pea. Then I saw another. . . ."

Since that first strike, prospectors have continued to scour the West for gold. The scale of their quest and its methodology have changed, in some cases only a little, in others beyond recognition. The forty-niners used simple methods to recover lumps and chunks of gold from streambeds or high-quality veins in the rock. Serious gold miners today employ sophisticated chemical techniques and equipment, including specialized metal detectors, to recover microscopic quantities of gold from low-quality deposits.

Gold nuggets once panned from streams by hand, above, now are recovered by modern technologies, such as the Knelson Concentrate Table, right, at use at Ontario's Hemlo Gold Mine. The machine vibrates and rocks back and forth, separating gold ore from slurry.

PATRICK ENDRES/ALASKASTOCK.COM (UPPER LEFT); © PAUL A. SOUDERS/CORBIS (RIGHT)

Forty-niner gold mania spawned the satiric lithograph, above, of a gold hunter heading for California.

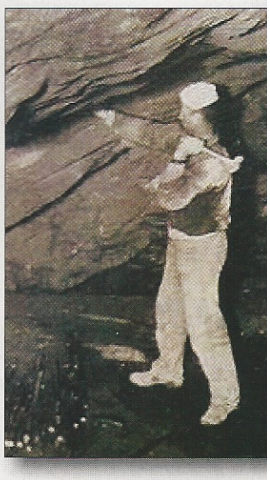
COURTESY OF THE CALIFORNIA HISTORY ROOM, CALIFORNIA STATE LIBRARY, SACRAMENTO, CALIFORNIA

Gold prices, too, have waxed and waned, influencing the pace of mining. Between 1935 and 1968, the federal government set the price of gold at $35 an ounce. By the 1950s and 1960s, that low price had closed many mines, though some have reopened in the last few decades as gold prices have climbed. Today, with gold at more than $900 an ounce, many operators look to a bright future, with tools and practices the forty-niners could not have imagined.

In the 1840s and 1850s, miners waded in icy rivers, swirling pans and shaking sluice boxes to separate the elusive gold flecks and flakes from river-bottom sand and gravel. Only after they had extracted the easy gold did miners begin to trace streambed or placer gold back to its sources. What they found under the California foothills—the famed Mother Lode—was a vast treasure of metal locked in rocky seams deep underground. Sinking shafts to reach the seams required much more capital than panning; no individual could finance or run a hard-rock mine alone. Underground mining changed the lives of prospectors, forcing many to become corporate employees. At best, they worked for shares; most labored for a weekly paycheck. And as with so many other industries, mining technology evolved more quickly under the auspices of companies rather than individuals.

British miners from Cornwall brought knowledge vital to developing hard-rock mining in the American West. These "Cousin Jacks" had hundreds of years of experience mining copper and tin. At the height of hard-rock mining in California, the majority of underground miners were Cornish. Whether in Cornwall or California, conditions were harsh. Historian Don Baumgart observed of the Cornish workers, "They seldom saw the sun; their complexions were pale and bodies stunted from crawling into narrow spaces and working in a day-long cramped position, hammering at the granite by the light of a single candle. Some Cornish mines were so deep a man might have to climb ladders continuously for an hour to reach the surface." Life for the miner, wrote mining chronicler Arthur Todd, involved "endless physical toil and often marginal poverty."

Mining technology in those days was very simple. Early underground



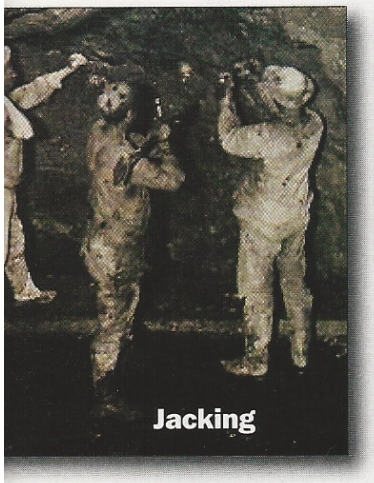
Early gold mining technology: Individual prospectors spent long hours stooped over pans, shaking away sediment to leave—if they were lucky—heavy nuggets of gold. Larger operations often employed "solucing" or sluicing, in which a long, wooden trough with bars or "riffles" across its bottom separated gold from lighter sand and mud. Underground mining relied on miners "jacking," or drilling holes for dynamite charges. Mules hauled ore cars on tracks to crude elevators. The miners themselves climbed long ladders to access horizontal tunnel shafts.

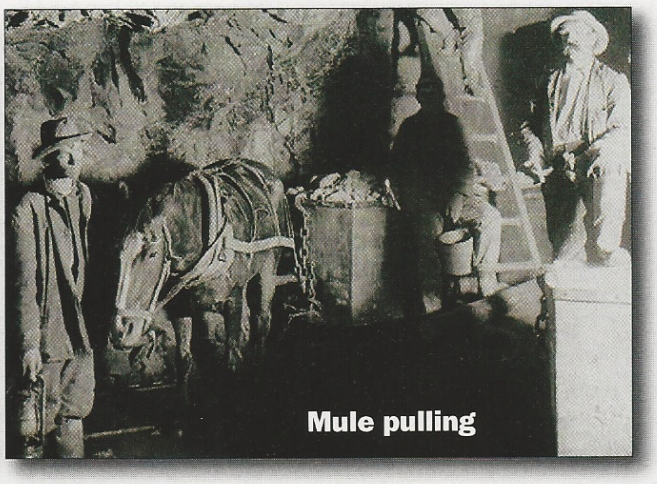
FRANK AND FRANCES CARPENTER COLLECTION (LIBRARY OF CONGRESS)

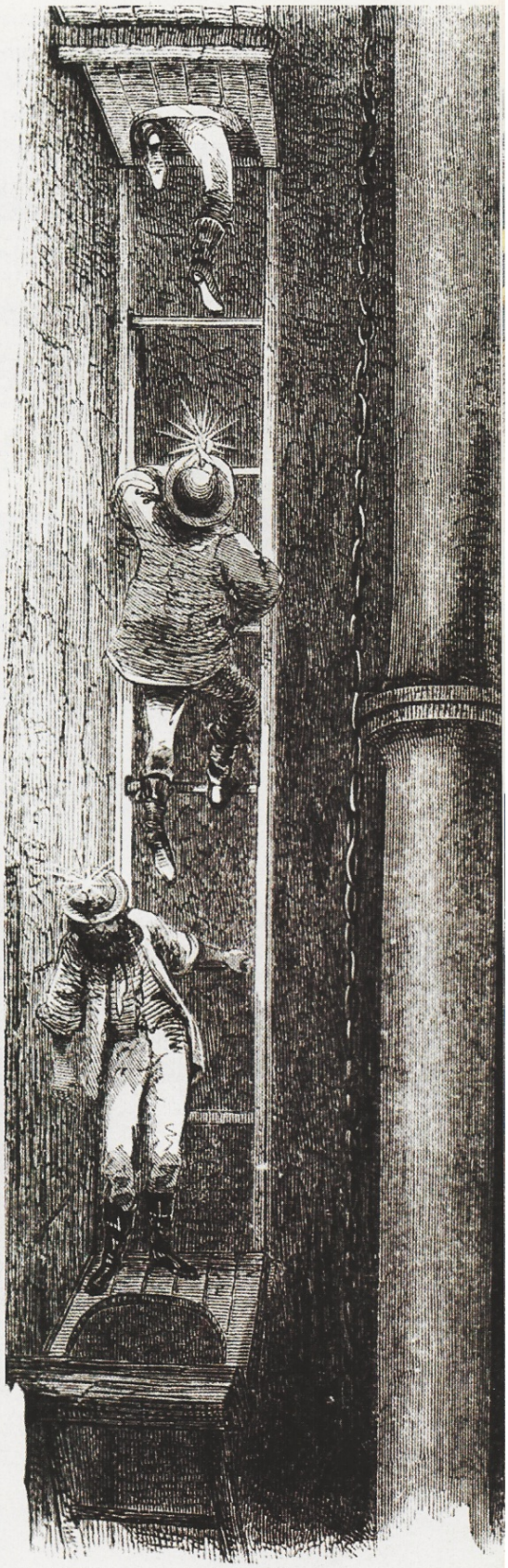
miners used hand tools to drill holes in the rock for placing explosives. One man would hold a steel drill while another miner pounded on it. Sometimes a miner labored alone. Once the hole was deep enough, explosives were inserted and the rock blasted away. The broken rock was then shoveled or mucked into ore cars and taken off. The process was repeated: Drill, blast, muck. In this way new tunnels or drifts were made or promising veins followed. Gunpowder was replaced in the 1870s by Alfred Nobel's far more powerful and efficient dynamite. Another chronicler of the era related the danger and determination that exist to this day: "Except for the lights in our hands all is dark, and as still as the tomb, with the exception of the distant creaking of a pump, and the steady dripping of some water at our elbow. Rock here, there, and everywhere. For several years men have been picking and drilling and blasting through solid rock; by day and night; in winter and summer; led forward by the talismanic power of gold—or at least by the hope to obtain it. Hard rock, hard work, and often very hard prospects; although combined with difficulty and danger, have never for a moment daunted or dismayed them."

Powered drills replaced hand tools in many mines in the 1870s, greatly improving efficiency. Simon Ingersoll's new steam-powered drill rotated the bit after every impact, speeding its penetration into the rock. Arthur Hawkesworth and Charles Burleigh also developed drilling rigs. The new drills unfortunately created more rock dust, which brought on silicosis, an often fatal lung disease. Half of the 19th-century miners in the West were said to have contracted it. Water-flushed drills in the 1890s helped somewhat, but not all mines used them. Today electrically driven tools can hold several drills at a time to the rock face; these jumbos or multiple jumbos made their debut in 1931 during the building of the Hoover Dam. Instead of a single blast of dynamite, a series of charges are consecutively fired by computer control in contemporary mines.

After the early miners mucked out the ore, it was time to crush it to powder, the first step in liberating the gold from its host rock. This was usually achieved with gigantic stamp mills, which crushed ore under cast-iron weights. Although they dated back to the 12th century, Virginia City, Nevada's James McFarland, and the Joshua Hendy Iron Works Company of San Francisco were among the first to adapt the technology to gold and silver. Early models used steam engines to turn a crank that rotated a battery of stamps. The noise was terrific, especially in towns where


Jacking


Mule pulling


COURTESY OF THE NORTH CAROLINA STATE ARCHIVES

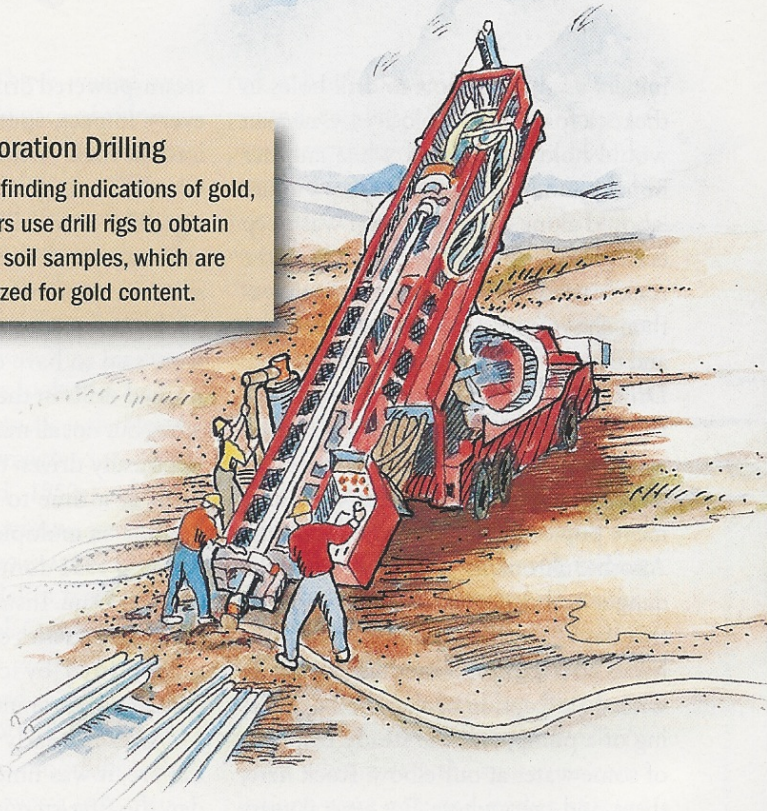
DISCOVERY AND EXCAVATION

Exploration

The gold mining process begins with geologists discovering evidence of a deposit.

Exploration Drilling

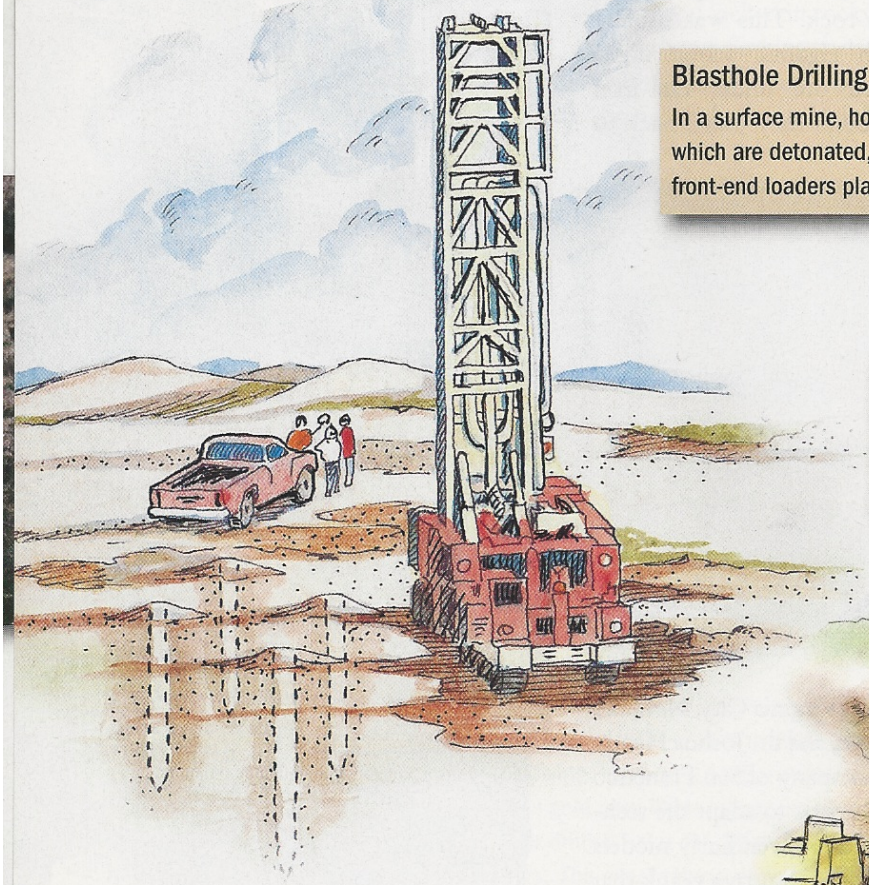
After finding indications of gold, miners use drill rigs to obtain deep soil samples, which are analyzed for gold content.



OPEN PIT MINING

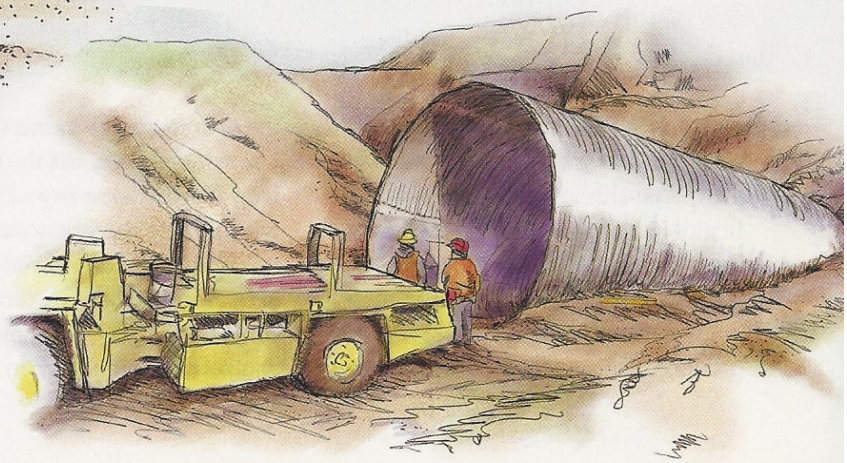
Blasthole Drilling

In a surface mine, holes are drilled in the pit, then filled with explosives, which are detonated, leaving piles of loosened soil. Large shovels or front-end loaders place the gold-bearing soil into haul trucks.



Underground Mining

Miners reach metal deposits via shafts, or "adits," which in turn branch off into smaller tunnels, or "stopes." Trucks remove ore loosened by explosions for processing above ground.



dozens of stamps operated. It was said that a visitor could find his way to Mariposa, California, simply by following the noise of the mills.

Once crushed, the gold was separated through gravity by washing or collected with mercury, which amalgamates with gold. The mercury was later driven off by heat in a still-like device called a retort, leaving some gold behind, although this inefficient process often lost between two-thirds to four-fifths of the metal put through. By comparison, today's recovery methods frequently exceed 98 percent.

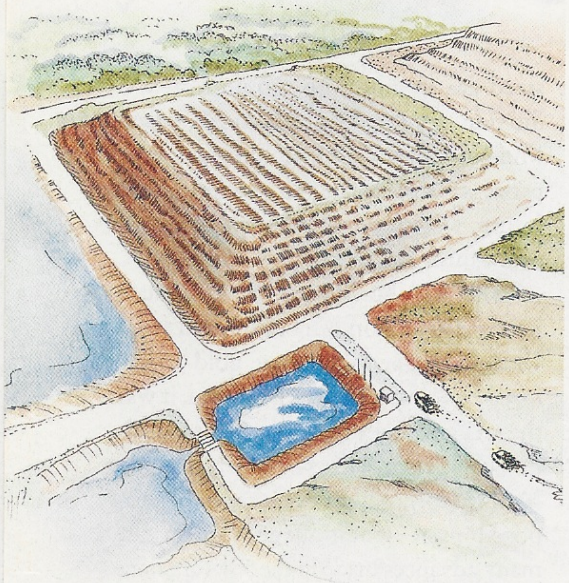
As crushing and extracting methods evolved, so too did the gear a miner used. Early gold miners had no safety or rescue equipment, used candles for light, and kept a canary to detect poisonous gas. Protective clothing is mandated today, from hard hats and gloves to steel-toe boots. In case of a cave-in, contemporary miners use Self-Contained Self-Rescuers (SCSRs), breathing apparatuses that scrub bad air clean and provide oxygen for at least an hour.

For lighting, carbide lamps replaced candles. Calcium carbide mixed with water produces acetylene, which was burned to produce light. Still more recently, lamps with tungsten halogen bulbs are replacing carbide. To detect bad air, companies such as Industrial Scientific and Bacharach Inc. make iPod-sized gas monitors to monitor carbon dioxide levels. The Idaho-Maryland Mine in Grass Valley, California, in the process of preparing to reopen in the future, will employ many of these new procedures and techniques.

The Idaho-Maryland produced nearly 2.4 million ounces of gold from 1862 to 1956, when low gold prices forced its closure. During that era, it was the second-largest gold producer in California. Under its new owner, Emgold Mining Corporation of Canada, the proposed mine would benefit from the many advances made in the 50 years since

A worker at the Ruby Mine, in Eureka, Nevada, right, prepares blast cord that will detonate 154 charges. Viceroy Gold's Castle Mountain open-pit mine near Ivanpah, California, below, produced 1.24 million ounces of gold between 1991 and 2001.

COURTESY OF THE CALIFORNIA STATE MINING AND GEOLOGY BOARD (RIGHT); AP PHOTO/ DOUGLAS C. PIZAC (TOP RIGHT)



At Barrick's Ruby Hill Mine in Nevada, below, and Peru's Pierina Mine, inset, irrigation drip lines sprinkle a weak cyanide solution atop piles of crushed ore placed on lined pads in a process called "heap leaching." The percolating solution leaches gold from the rock, then flows into holding tanks.

it was closed. Mining techniques are more efficient, the mine's complex geology is better understood, and miners are learning how to repurpose waste rock.

Mines today are much better designed. Gone are the manskips, tramlike, sled-on-rails affairs that sent dozens of miners at a time hurtling down to lower levels. Well-constructed and regularly inspected elevators, called cages, now deliver men to the workings. At the Idaho-Maryland, a decline—a sloping road inside a tunnel 18 feet wide and 16 feet high, large enough to accommodate a truck and a conveyer belt for hauling out ore—is slated to be built. Here an underground miner could literally drive to work. Gone too are the days when ore-cart-hauling donkeys and mules might have lived out their lives underground. They've been replaced with equipment, such as Scooptrams™, vehicles that load, haul, and dump broken rock and ore. These 40-foot-long front-end loaders carry eight-cubic-yard buckets and roll on six-foot-tall tires. Former hard-rock miner Stephen Voynick says such equipment allows "a single miner to move more muck than any ten miners could have dreamed of moving 50 years ago. While such machines also reduce the chance of injury by reducing the number of man-hours necessary to remove a given tonnage of muck from a heading (the working end of a tunnel), they simultaneously introduce new hazards that were not present before: the danger of enormously heavy equipment rolling through the narrow drifts, and the omnipresent fire hazard created by the hundreds of gallons of flammable petroleum products sloshing around inside the machines."

Modern ventilating systems are another improvement, ensuring enough air for miners to breathe (in decades past, workers nipped on compressed air from pneumatic lines). Still, mining remains a

COURTESY MET SOC

dangerous occupation. The same well-vented condition may at times be a curse. "Today, with vastly more efficient vent systems powered by enormous fans moving great quantities of air through well designed flow patterns, the deadly products of combustion are also distributed quickly and efficiently throughout the underground," Voynick points out.

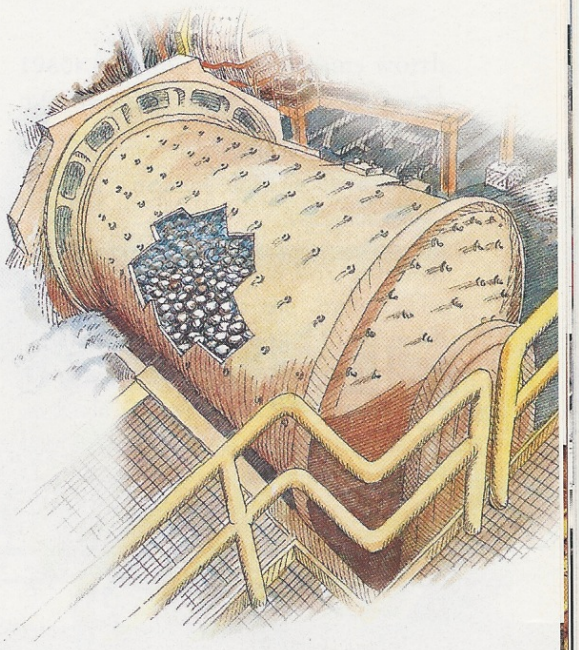
The geology of gold has also come a long way since the 1850s. As with diamonds, hard-rock gold tends to occur under specific conditions around the world. Emgold noticed striking similarities between the geology at the Red Lake Mine in Ontario, owned by GoldCorp Inc., and that of the Idaho-Maryland Mine. The research at Red Lake has helped Emgold understand the geologic complexities of its Nevada City property.

What about the waste rock, the bane of every mining operation? Every hard-rock mine produces waste—more than 11 billon pounds from the Idaho-Maryland Mine in the early days, when the excess rock was used for road building or thrown into nearby canyons. Today miners must work not only hard but also smart. Emgold will use geologist Ross Guenther's patented process to turn tailings into ceramic products, including high-quality floor and wall tiles, roof tiles, bricks, pavers, and other building materials. These ceramics are expected to produce half the mine's income, only 50 percent coming from gold. While your next driveway might not be paved with gold, the pavers could come from a gold mine.

Gold miners seek their precious metal close to the surface, too, in a process that the trade calls open-pit mining. Most folks know it as strip mining, a technique that would arouse awe and envy in any old forty-niner. The open-pit method is employed where the gold lies relatively close to the surface and distributed throughout its host rock. Instead of following a vein, open-pit mining processes vast quantities of material dug down from the surface. Such diggings can create gigantic pits visible from space.

Open-pit gold mining is a relatively recent phenomenon, because the miners of the past could not economically recover gold in microscopic amounts. Open-pit machinery actually evolved in the coal and copper industries, as increasingly bigger equipment made mining more efficient and therefore more profitable. Giant excavators and 85-ton trucks the size of small houses can dig and move tons of low-grade ore at a time; the material is then chemically processed. The Mesquite Mine in the low desert of Imperial County, California, is a good model of how extracting gold through chemical reaction has evolved.

Open-pit mining for gold became popular in the 1980s, when high gold prices yielded returns from even low-grade ores. It has produced 3 million ounces of gold since 1986 by processing 154 million tons of ore, less than one ounce in 50 tons. That's 26 times the rock that the Idaho-Maryland mine generated over its entire 100-year life. The Mesquite Mine, owned by Western Goldfields Inc., recovers gold by heap leaching, an extremely efficient chemical technique using sodium cyanide and carbon. With it, the mine processes ore that averages a minuscule 0.026 ounces of

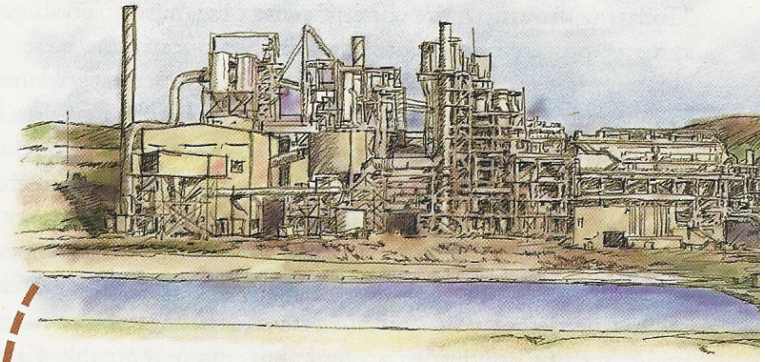


As the large drum of a milling machine turns, below, at the Newmont Phoenix Mine, near Battle Mountain, Nevada, internal studs in the walls and heavy steel balls crush the gold ore into a fine powder or slurry.

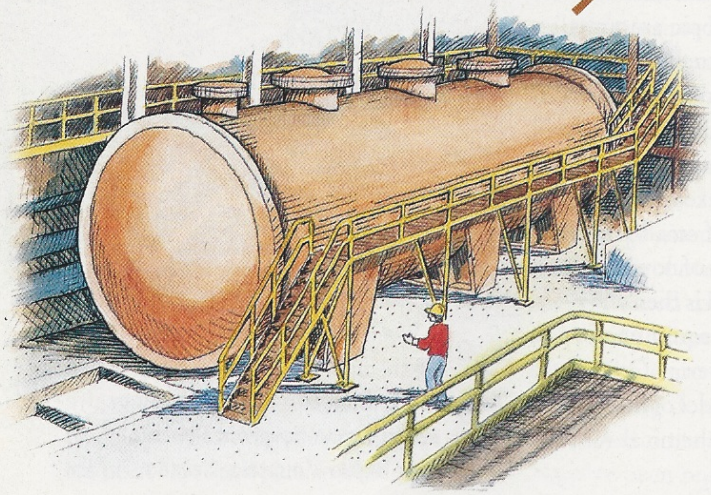
AP PHOTO/NEWMONT MINING, ANDREW CRAIG

ORE PROCESSING

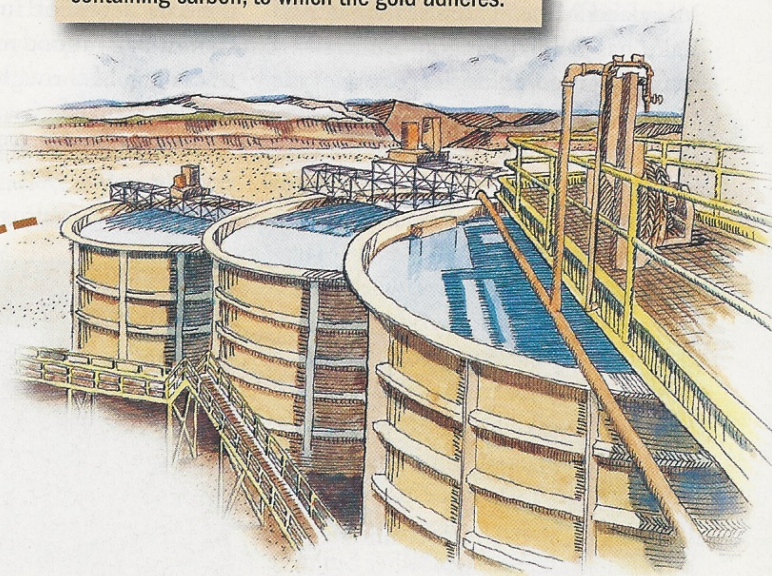
The Roaster
Ore in the form of dry powder is passed through a roaster, where it is oxidized.



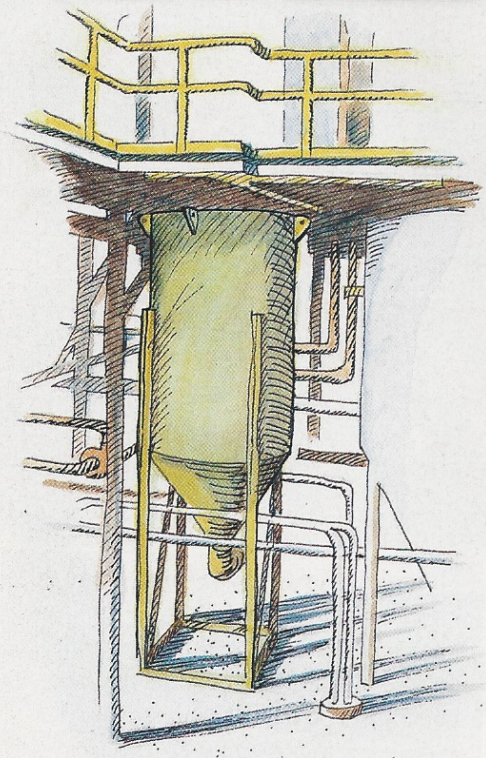
Oxidation
Certain types of ores require processing by oxidation under pressure in a large autoclave.



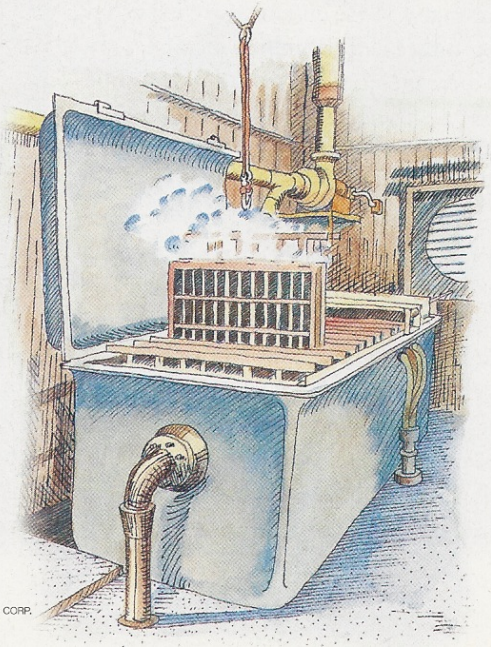
Leaching
Thickened slurry passes through leaching tanks containing carbon, to which the gold adheres.



Stripping
Inside a stripping vessel a hot caustic solution removes the carbon from the gold.



Electrowinning
Inside a tank, electrowinning cells deliver a current to the gold-bearing solution, separating out the precious metal.



COURTESY OF THE NEWMONT MINING CORP.

gold per ton of rock. (A dollar bill weighs ten times that amount.) Early prospectors probably would not have realized that the rock contained gold at all. Treating gold-bearing ore with cyanide was developed in 1887 by Scottish chemist John Seward MacArthur, and the process was improved by Phillip Argall in the 1890s. In 1948 John Benjamin Zadra, working for the U.S. Bureau of Mines in Reno, Nevada, began perfecting the process in use today, adding carbon with the cyanide. Recovery rates may reach 40 percent higher than the older mercury-recovery system was able to achieve.

Heap leaching is fairly straightforward. Low-grade ore is spread out on a slightly sloping impervious pad or liner. Cyanide is sprinkled on or otherwise applied to the ore, dissolving the metallic gold into a solution that leaches out at the bottom of the ore heap and is then collected and processed. Cyanidation makes it possible to recover "invisible gold" at the micron level. (A white blood cell, by comparison, measures 10 microns across.) Western Goldfields is currently reprocessing heaps left from the previous owners and expects to glean 14,000 ounces. But they plan to mine and leach new ground by April 2008. Their goal is to average 165,000 ounces of gold per year over the following nine and a half years.

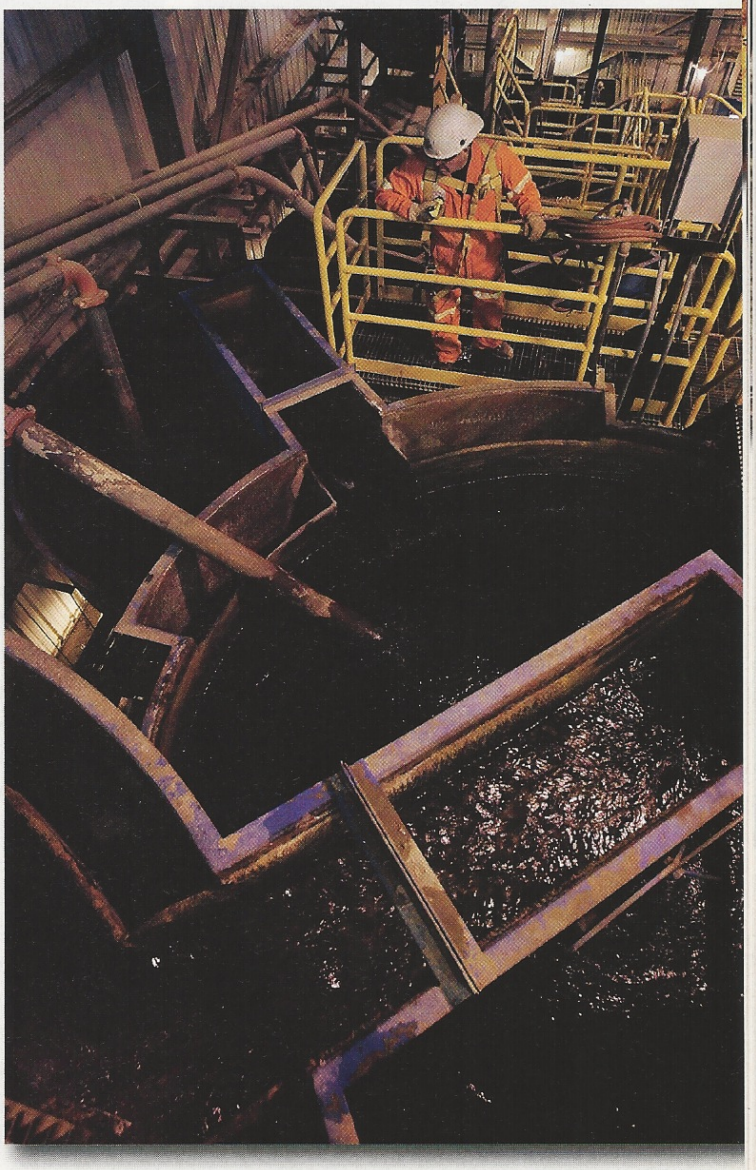
What about the spoil, the great heaps of material left after the gold has been removed? Western Goldfields intends to use theirs to seal a proposed "megadump" landfill for Los Angeles, California. According to the Center for Land Use Interpretation, the tailings from the Mesquite Gold Mine would come by train, forming "a pile as high as a 30-story building, and over three miles long over the coming years." While not exactly turning trash into treasure, this use of the waste rock comes fairly close.

Open-pit and underground mines account for a considerable percentage of gold production, but gold can be recovered in other ways such as placer mining, the extraction of gold from past or present watercourses. As writer Edward Buffum explained in 1850, "The beds of these rivers are composed of huge rocks, tumbled together as they are upon the banks; and it is in the crevices and pockets of these rocks that the gold has secreted itself. Where the stream is narrow and the current strong, the probability is that there is little gold; but where it expands, and the water becomes more quiet, the gold has settled peacefully, there to remain till the hand of some irreverent Yankee shall remove it from its hiding place."

Small and relatively simple portable suction dredges, operated by one person or at most two, can now dredge the gravel bars of streams and rivers for gold. Their development, and that of much other amateur gold-mining equipment, began in earnest in 1975, when Americans were allowed to own and sell gold without restriction for the first time in many years. The price of an ounce of gold had also soared since the late 1960s, making many streams worth mining again.

In dredging, a diver works below the water, manipulating a vacuum hose of up to eight inches in diameter that sucks water, sand, and gravel from the streambed into a sluice box mounted above the water on the dredge. The sluice box's bottom is "riffled" with short metal bars, set every few inches at an angle against the flow of water. The bars collect gold, which is 19 times heavier than water, while the lighter sand and gravel washes away.

Gone are the gigantic and often destructive clamshell, dragline, and bucket



Gold in thickened slurry binds to carbon inside leaching vats, right, at Barrick's Ruby Hill Mine outside Eureka, Nevada.

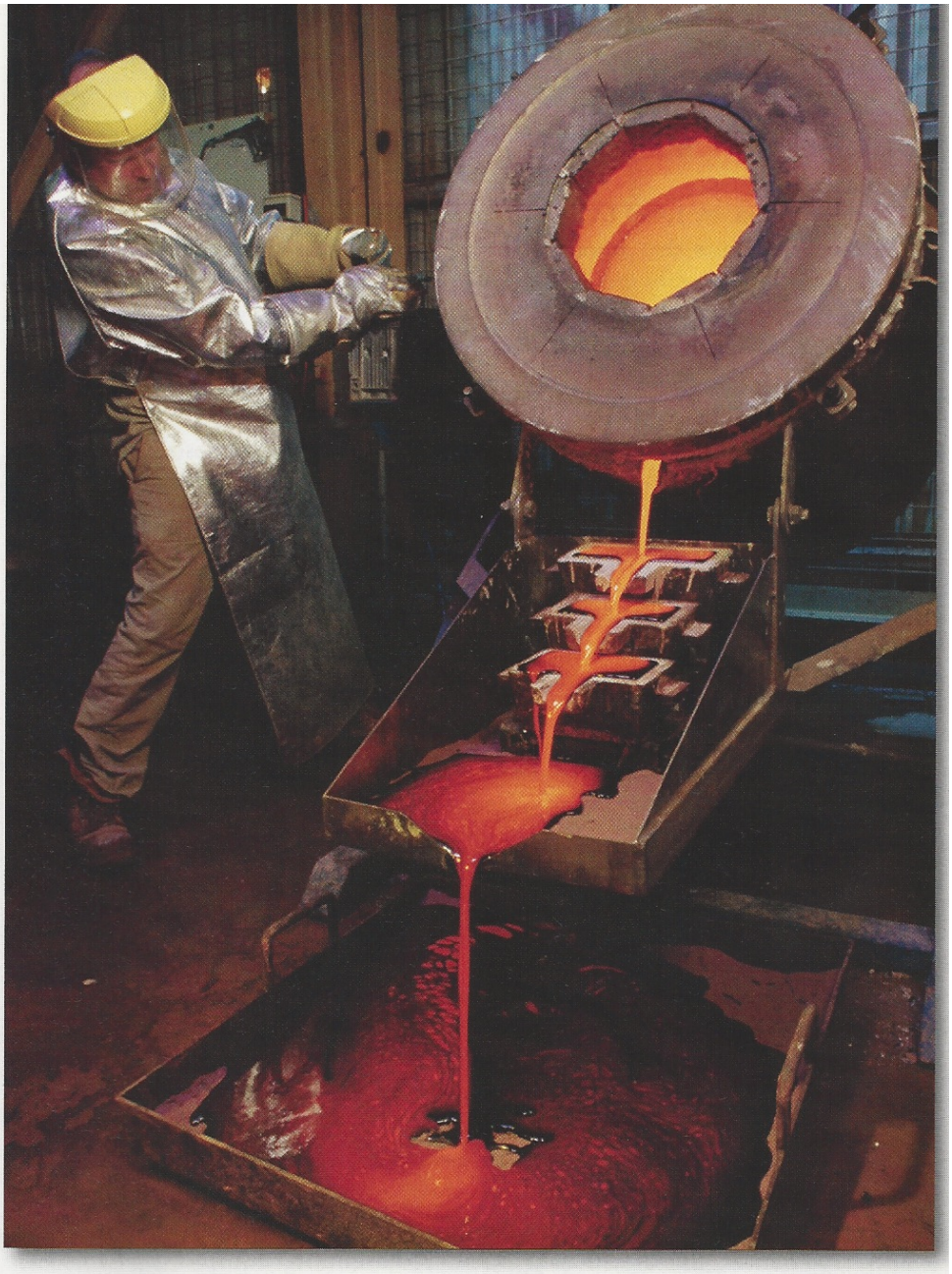
AP PHOTO/ DOUGLAS C. PIZAC

dredges of the past. The largest of those Brobdingnagian monsters, the 500-foot-long Bima, scooped up four tons of material in every bucket. But scouring a riverbed or ocean floor with such equipment gravely degraded the environment and so is no longer permitted. It is with smaller machines, not larger, that American gold dredging will continue.

The operators of small dredges are mostly amateur miners, not professionals. Dan Cordes is one. "My best day ever was a three-quarter-ounce day," he says. "Which ain't much. But I was damned happy to find it. That was on the middle fork of the Yuba River. The following day I got a third of an ounce. What allows me to go gold mining is that I do maintenance at the place where I live. At the end of May, early June, I had rent covered for a three-month period. So I didn't need to earn a lot. The day I pulled a third of an ounce; what's that, a hundred and a quarter? A hundred and fifty bucks? Less than two hundred dollars. For that amount I can afford to retreat to the mountains to do this. If I had a family I don't know how I could possibly provide for them. There's other rewards, though, seeing deer, fox, bears, and bald eagles. I think for me dredging is a way to get the hell away from civilization."

Some equipment and practices come with a pedigree, a long history of improvements. Metal detecting is an exception: gold detectors have only been around for 30 years or so. But metal detectors themselves date back at least to 1881, when Alexander Graham Bell invented one to try to locate an assassin's bullet in President James Garfield's body.

World War II soldiers used handheld detectors to sweep battlefields for land mines. But these devices really evolved years after the war, as prospectors flocked to various parts of the West to search for uranium with radiation detectors called Geiger counters. Olive and Ken White Sr. built one per day of their own design. The counters proved popular, and in seven years White's Electronics had 65 employees.



Extraction of gold from ore usually yields purity of 990 parts out of a 1,000. Melted gold is poured into forms, above, to make ingots that can be stored or shipped to banks, mints, and jewelers.

In 1958 the U.S. government announced it would no longer buy uranium. Persuaded by one of their dealers to make a machine for treasure hunting, White's produced a general-purpose metal detector in 1959. The company blossomed and is still in business. Gold detectors debuted in the mid-1970s, as electronic technology gained the capability to discriminate among different metals, first with beat frequency oscillators (BFOs), which have long since given way to the widely used very-low-frequency (VLF) detectors. These VLF models are widely used, although a newer technology, pulse induction (P/I), is making itself felt. A VLF detector, sometimes called an induction balance machine, generates a steady, short-range radio wave at its search head and broadcasts it into the ground. A second loop in the head picks up the reflected signal, its microprocessor noting any changes between what was transmitted and received; variations in the electromagnetic field cause the speaker to sound off.

Every type of metal has its own sonic signature. A tin can may make a loud squeal, an aluminum pull tab a sharp rasp, and a small gold nugget a soft "zip." Nickel and lead sound maddeningly similar to gold.

Amateurs and professional prospectors alike use detectors. And no mine has used metal detectors and radio imaging equipment more than the Original Sixteen to One Mine in Alleghany, California. Started in 1896, the Original Sixteen to One crushes and processes ore when necessary, just as most hard-rock mines do. But its specialty is finding gold in its host rock—in this case white quartz—to sell as mineral specimens or to make into jewelry. Since 1992 the Sixteen to One has been using metal detectors, which have given it some notable successes. The biggest strikes were in 1993, when miners pulled out 2,500 ounces of gold, and a string of four shifts in 1995 when one tunnel yielded 5,000 ounces.

Entrepreneur Michael Miller, president and leading shareholder of the Sixteen to One, relishes the clear but difficult mission of wresting gold from this century-old mine. Deep in a tunnel, he examines the milky white quartz of a wall, glowing softly in the light of a carbide lamp. Somewhere, perhaps an inch in, perhaps ten feet away, lurk ounces or pounds of gold. His metal detector sounds off, indicating a spot to check. Miller is upbeat but guarded. "Metal detectors are great," he says, "but they often signal when they shouldn't."

Recognizing the limitations of conventional metal detection, engineers at the Sixteen to One began using ground-penetrating radar, as well as another radio imaging technology known as cross-borehole radio tomography, which employs a transmitter in a hole at one level and a receiver down a hole at another. An operator passes a low-frequency radio wave between the two to reveal anomalies in the rock. The first tomographic geophysical tools were developed in the early 1980s, primarily by Stolar, a company founded by Larry Stolarczyk, which holds at least 10 patents in the field; coal-mining applications are the company's primary focus.

Miller describes how tomography worked when the Sixteen to One miners tried it—and the tantalizing results. "They had a sender at the 2,200-foot level and a receiver on the 1,700-foot level. They would then move the receiver every 25 feet, shooting a new radio wave each time. They collected the data, took it back to Colorado, then sent us the results. We mined three of the four targets. The first was a vug, which was an opening in the rock; the second a horse, which is material dragged into a vein millions of years ago; and the third was an old mucking machine, which had been left behind and become buried." So tomography can read the rock pretty well, but can it find a mass of gold? Not necessarily. The future for prospecting at the Sixteen to One seems to be for handheld metal detectors that can penetrate the rock deeper than their current four feet.

Miller is optimistic. He thinks genuine improvements have come since 9/11, as security-minded agencies and corporations push the development of better imaging machines. Soon, he believes, they will be able to look farther into rock than ever before. "Right now, things are happening. Equipment has really advanced. There's been money coming into the system to do much more serious or different types of detection. I'm 100 percent convinced that the technology is now there. What will take a little bit of time and tweaking is the software. And that will only come with experience. At some point we'll be able to tell whether it's a geological anomaly or whether it is gold, as we start detecting 20 feet into beautiful quartz rock."

A small operation, the Sixteen to One struggles to stay in business. It is not enough to discover gold; the company must be able to recover it economically. Keeping water out of the mine highlights this problem. Miller believes large deposits still exist at the flooded lower levels; the high cost of pumping, however, stalls further exploration. Still, there are plenty of tunnels and promising areas to investigate above the current waterline. And it is primarily by electronic investigation that prospecting in the Sixteen to One will continue.

Rare, easily worked, softly lustrous, incorruptible, and enduring, gold has always captivated humans for good and evil.

One hundred sixty years have passed since James Marshall's discovery precipitated the California Gold Rush. Thanks to modern recovery methods, gold continues to be an important resource in America. According to the Mineral Information Institute, "The United States is the world's second largest gold producer, capable of meeting its domestic gold needs while exporting approximately 20 percent of its production. The industry directly employs nearly 17,000 people, and in gold-producing states the total job impact reaches over 71,000 people including local contractors, vendors and suppliers." These ever-evolving practices make gold's future look golden indeed.

Tom Farley, a Sacramento, California, freelance writer and amateur prospector, last wrote for this magazine on the history of the mobile phone in Winter 2007.