From Copperas to Cleanup

The History of Vermont's Elizabeth Copper Mine

Milestone Heritage Consulting

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Front cover: haul truck at North Open Cut: U.S. Environmental Protection Agency. Rear cover: miners examining ore sample: Strafford Historical Society. Other cover images credited elsewhere within.

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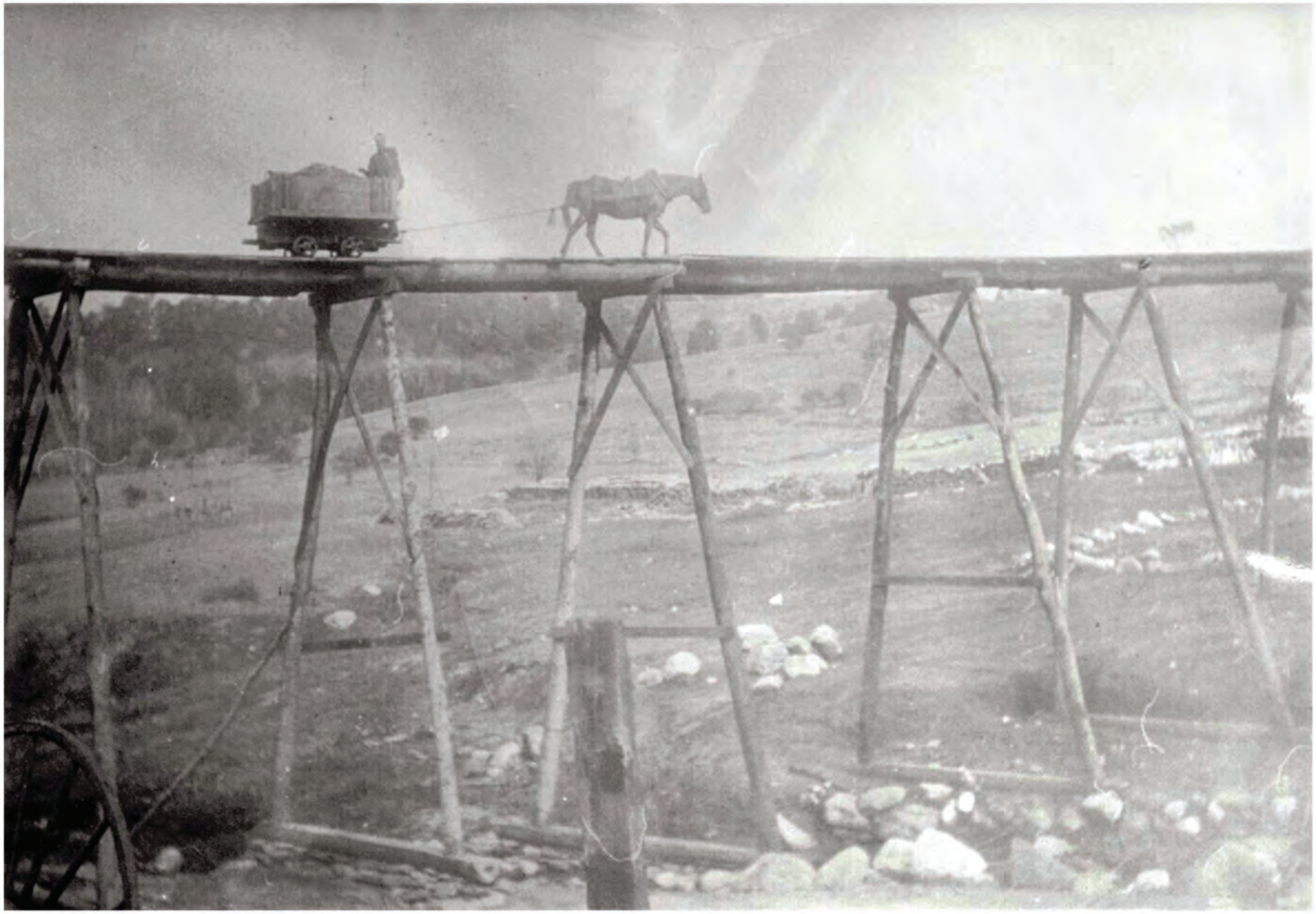

Elizabeth Mine, horse hauling ore car and miner on trestle, 1890s. Source: Strafford Historical Society.

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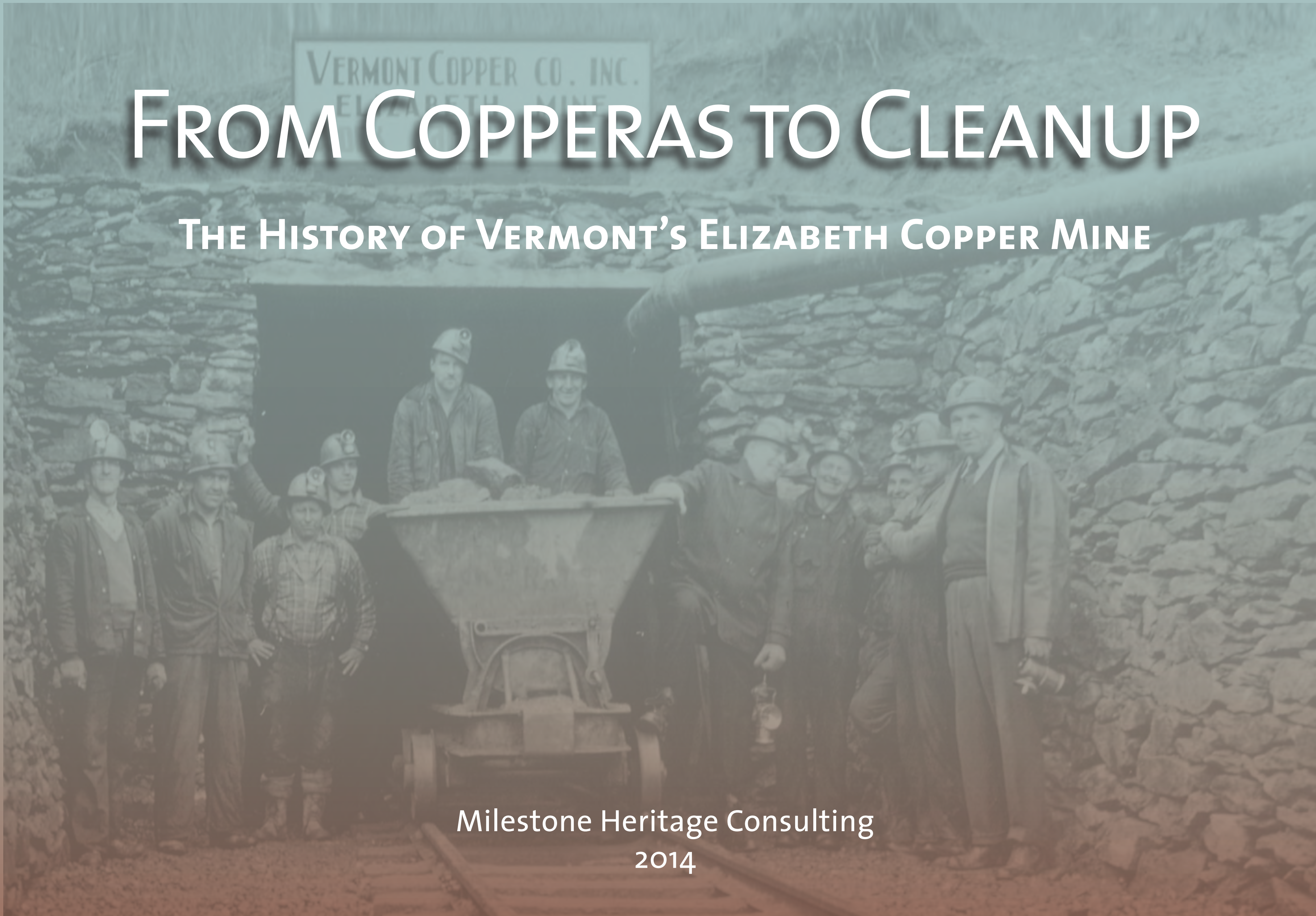

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Elizabeth Mine, 1950s scene of miner drilling overhead with compressed-air drill. Source: Strafford Historical Society.

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Introduction

The Elizabeth Mine in South Strafford, Vermont, is one of New England's largest and most unusual historic industrial sites. During almost 150 years of operation between 1809 and 1958, it was the scene of technological developments in the American copper and chemical industries and produced nearly 50,000 tons of copper for the American Industrial Revolution and the Civil War, two world wars, and the Korean War. It was, for a time, the largest producer of copperas (iron sulfate) in the United States and, in the twentieth century surpassed the nearby Ely Mine in Vershire as the largest copper mine in New England. A century and a half of mining left behind a dramatic industrial landscape, which was largely intact.

The boom-and-bust nature of the mining industry has created a legacy of abandoned mine sites across the United States. The Elizabeth Mine and other Orange County, Vermont, copper mines are among the numerous mine sites abandoned without reclamation. The remaining mine waste materials left exposed to water and oxygen released acid runoff with high concentrations of metals, contaminating nearby watercourses and affecting their ecology. In 2001, the U.S. Environmental Protection Agency (EPA) designated the Elizabeth Mine a "Superfund" site to allow federal resources to be made available for study and cleanup.

The Elizabeth Mine's history and future were important to the people of Strafford and the State of Vermont. The site was a powerful, tangible expression of human effort, industrial technology, and attitudes toward natural resources, as well as a potential source of historic and archaeological data. In 2001, the mine site was determined eligible for listing in the National Register of Historic Places, and the EPA worked closely with the Vermont State Historic Preservation Officer and other stakeholders to address cleanup impacts on historic properties under the National Historic Preservation Act. *From Copperas to Cleanup* presents, in words and pictures, the story of 150 years of industrial activity at the Elizabeth Mine and how the EPA and its project partners reclaimed the site and documented its history.

Vermont mining historian and author Collamer Abbott looks into the North Open Cut at the Elizabeth Mine, 2000. Source: Matt Kierstead.

This popular report was completed in partial fulfillment of a memorandum of agreement among the U.S. Environmental Protection Agency, the Vermont Division for Historic Preservation, and the Vermont Department of Environmental Conservation to address adverse impacts to historic resources resulting from the cleanup of the Elizabeth Mine Superfund site. This report was prepared by Milestone Heritage Consulting, subcontractor to Nobis Engineering, Inc., under contract to the U.S. Army Corps of Engineers, New England District, to support the EPA.

Author Matt Kierstead has over 25 years of experience exploring, studying, and documenting the Orange County copper mines. The author would like to acknowledge the following people: the late mining historian Collamer Abbott of White River Junction, Vermont; the late historian Gwenda Smith of Strafford, Vermont; Bob and Stefanie Johnston of Strafford, Vermont, and the Strafford Historical Society; mining engineer and historian Johnny Johnsson of Finksburg, Maryland; archaeologist Suzanne Cherau of PAL Inc. in Pawtucket, Rhode Island; Vermont State Archaeologist Giovanna Peebles; Ed Hathaway and Karen Lumino of the EPA; Kate Atwood of the U.S. Army Corps of Engineers, New England District; John Schmeltzer and Linda Elliott of the Vermont Department of Environmental Conservation; Bob Seal, Nadine Piatak, and Jane Hammarstrom of the U.S. Geological Survey; Chris Adams of Nobis Engineering Inc.; book designer Ron Toelke of Toelke Associates, Chatham, New York; editor Glenn Novak of Richmond, Massachusetts; and everyone else who provided assistance, guidance, and information.

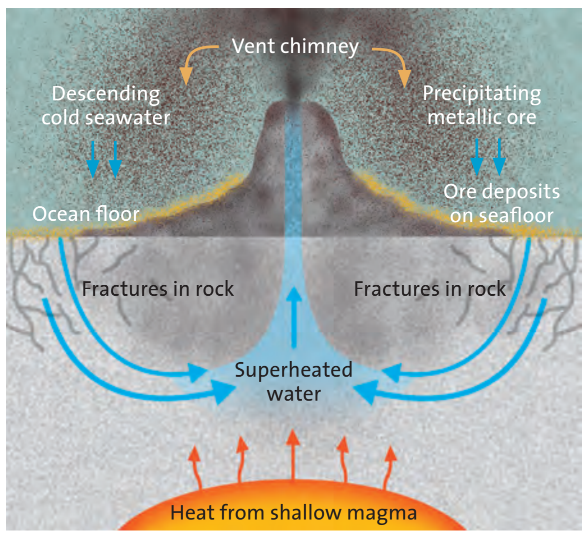
Sample of chalcopyrite (copper iron sulfide) ore taken from underground at the Elizabeth Mine in the 1950s, with copper penny for scale. Source: Matt Kierstead.

From Ocean to Mountain: Orange County Copper Geology

The Elizabeth Mine is about ten miles north of White River Junction, in southeast Orange County, Vermont. The mine site straddles Mine Road, approximately two miles southeast of the village of South Strafford. All former mine land is now private property.

The Elizabeth Mine was dug from the Gile Mountain Formation within Vermont's eastern Green Mountains, a range of the Appalachian Mountains. The Appalachians, which stretch from Alabama to the Gaspé Peninsula in Canada, were formed by a series of orogenies—mountain-building continental collisions—that began about 480 million years ago in the early Ordovician period. The rocks of the eastern Green Mountains were created from large areas of underwater sedimentary and volcanic ocean crust, formed near a seafloor continental plate margin during the Silurian (443–419 million years ago) and early Devonian (419–358 million years ago) periods. The rocks were metamorphosed and deformed by great heat and pressure during the Acadian Orogeny (roughly 375 million years ago). The Appalachians were once as tall as the Alps or Rocky Mountains, but were worn down to their present height through millions of years of erosion. Geologic activity in these periods formed and exposed Vermont's rich variety of building stones, ores, and industrial minerals, including granite, marble, slate, verde antique serpentine, copper, iron, asbestos, and talc. Vermont's extractive industries have their own history, traditions, historical sites, and, in many cases, still-active operations.

The Orange County copper ores are what geologists call "syngenetic seafloor massive sulfides," an important class of metal-bearing ores. These ores formed at the same time and place as the rocks in which they are found, on the seafloor in places where water circulated through broken volcanic rock close to shallow magma. The superheated, pressurized water leached metals from the rock and rose to the seafloor, where it billowed out through hydrothermal vents. There the metals precipitated onto the seafloor as the heated solutions cooled. These deposits were slowly buried by sediments and eventually thrust up into mountains and metamorphosed through tectonic activity along with their host rocks. These ore deposits tend to be massive, elongated, and closely bound between their surrounding host rock layers.



Cross-section of a typical seafloor hydrothermal vent. Source: Ron Toelke.

This type of ore deposit is found worldwide and is common throughout the Appalachian Mountains. The most productive deposits of this type in the United States were mined at Ducktown, Tennessee, between the 1850s and 1987 and were a major eastern U.S. source of copper, as well as sulfuric acid. The Ore Knob Mine in North Carolina was worked during the nineteenth century and last by Appalachian Sulphides Inc., after that company left the Elizabeth Mine in 1958. The 20-mile-long Great Gossan Lead deposit in Virginia was also mined for copper. The Davis Mine in Rowe, Massachusetts, was that state's deepest mine, at over 1,000 feet, and was a major U.S. source of pyrite for sulfuric acid manufacture between 1882 and 1912. Appalachian sulfide mines in Maine included a cluster of copper and zinc mines around Blue Hill that were mined intermittently between the 1880s and 1970s. The Callahan Mine at Harborside, Cape Rosier, which operated between 1968 and 1972, was the largest open pit metal mine east of the Rocky Mountains. Across the border in Canada, some of the largest zinc mines in the world operated until recently near Bathurst, New Brunswick.

Sulfide ore minerals are compounds of sulfur and various metals, usually iron, which form pyrrhotite or pyrite, known as "fool's gold," as well as ores of copper (chalcopyrite), lead, zinc, and other metals. The high sulfur content makes sulfide ore mines particularly susceptible to acid rock drainage problems.

Red Metal History: The American Copper Industry

Copper has been used by man for thousands of years. It is easily hammered into tools and ornaments when found in its soft, almost pure, "native" state. The word *copper* comes from the Latin *cuprum*, named for the Mediterranean island of Cyprus, where copper ore was found. Early Mediterranean and Middle Eastern peoples knew how to smelt copper and tin ores to make the alloy for which the Bronze Age is named. Smelting is the process of heating metallic ores in specialized furnaces with other materials to produce pure molten metal. Copper's unique combination of malleability, ductility, strength, and corrosion resistance made it ideal for weapons and containers. By the eighteenth century copper was used in coins, cannon, bells, statues, musical instruments, plumbing, hardware, and for sheathing roofs and ships. Copper is also very conductive, and by 1900 it was in great demand for the electrical industry.

A "Higley copper," an early colonial trading token minted by Samuel Higley in Simsbury, Connecticut, in 1737.

Except for some iron, most metals consumed in the American colonies in the seventeenth and eighteenth centuries were imported. Sporadic attempts were made to mine copper, but sulfide ores proved hard to smelt. Copper was mined at Simsbury, Connecticut, from about 1705 until the 1750s, and in the 1770s the mine became the notorious underground Newgate Prison. The Schuyler Mine in New Jersey was discovered about 1713, and the first steam engine in America was installed to pump water from the mine in 1755. Copper imports were cut off during the Revolutionary War, when the Liberty Mine in Maryland became a major domestic copper source.

After the Revolution, the American copper industry suffered from trade restrictions, lack of skilled labor, and poor transportation. The U.S. Navy needed copper sheathing for ship hulls during the War of 1812, but domestic industry could not meet the demand. Desire for self-sufficiency led to development of new copper mines and smelting attempts in the 1830s at places like Bristol, Connecticut, and South Strafford, Vermont. Domestic copper smelting remained a bottleneck. Until the 1840s, most U.S. sulfide copper ore was shipped to Swansea, Wales, and smelted in a complex, multistep process requiring skilled labor and great quantities of fuel.

The situation for the U.S. copper-smelting industry improved greatly in the 1840s. Protective import tariffs were enacted, and new canals and railroads connected coastal ports with the interior. Pennsylvania anthracite coal fuel and skilled Welsh labor became available. New coastal smelters opened in the 1840s in Maryland, Massachusetts, and New Jersey and smelted copper sulfide ore from Chile and Cuba, as well as from Ducktown, Tennessee, and Ely and South Strafford, Vermont. These northern smelters made copper for the Union during the Civil War, but closed in the 1870s in the face of western U.S. competition.

In 1841 Douglass Houghton discovered a rich source of native copper in Michigan's Upper Peninsula, already recognized as the source of widespread Native American copper trade. Artifacts believed to be made of Michigan native copper have been recovered from 3,000-to-2,000-year-old Vermont Native American archaeological sites. Large quantities of easily refined copper quickly made Michigan the largest U.S. copper source by 1850. In the early 1880s the richest copper deposits then known in the world were discovered in Butte, Montana, which eclipsed Michigan, producing over 40 percent of U.S. copper by 1890. Large-scale copper mining began in Arizona in the 1880s and outstripped Montana production by 1910. By 1920, almost half of U.S. copper came from Arizona.

The American West became a major world copper producer in the early twentieth century when mass-production methods were applied to large, low-grade ore deposits. Mining engineer Daniel Jackling was the first to apply railroads, steam shovels, modern explosives, and froth flotation milling to metal mining, at the Bingham Canyon, Utah, copper mine before World War I. Eventually this technology extracted 90 percent of the value in ores containing less than 1 percent copper. By the 1950s, 90 percent of all U.S. copper was mined from open pits west of the Rocky Mountains.

Copper was mined intermittently in the eastern United States for about 275 years, but total regional output was less than 5 percent of national production. A handful of eastern U.S. mines, including the Elizabeth Mine, reopened in the mid-twentieth century, when metal prices and wartime demand briefly made them profitable.

Vermont's Copper Belt: The Orange County Copper Mining District

Vermont's thirty-mile-long "Copper Belt" was the largest, most productive hard-rock underground metal mining district in New England. It included three mining locations: the Elizabeth Mine in South Strafford, the Ely Mine in Vershire, and the Eureka and Union Mines on Pike Hill in Corinth. Mining at all three places occurred in pulses over time based on demand for copper and technology to efficiently produce it.

The Elizabeth Mine operated from 1809 to 1958. It produced copperas, an important iron sulfate chemical, starting in 1809. It was the largest U.S. manufacturer for a time but production stopped in the early 1880s. Copper ore was mined, in several concentrated campaigns, between the 1820s and 1958. Copper smelting began with pioneering experiments by Isaac Tyson Jr. in the 1830s and included eight additional smelting efforts at six different South Strafford locations through World War I. The Elizabeth Mine was modernized for World War II and was one of the top twenty U.S. copper producers for part of the 1950s. It was by far the largest copper producer in Vermont, yielding about 100 million pounds (50,000 tons) of copper. The nearly 150 years of mining activity left behind considerable environmental impacts and a large and complex historical landscape.

The Ely Mine was active from the 1850s to World War I. It was a major mid-nineteenth-century eastern U.S. copper producer until the 1870s, when it was eclipsed by the copper mines of Michigan and the American Southwest. Copper smelting began at Ely in 1867, and the massive, 700-foot-long plant was the only place in Vermont where refined copper was made on a large scale. Ely village, a mining boom town of about a thousand residents, grew around the mine. In the 1880s the mine was the scene of the "Ely War," Vermont's largest and most dramatic labor revolt. George Westinghouse conducted smelting experiments at the mine about 1900, and a small amount of copper ore was processed during World War I.

The Eureka and Union Mines at Pike Hill were the smallest in Vermont's Copper Belt, operating intermittently from the Civil War through World War I. Copper ore from the Union Mine was taken to the Ely smelter by wagon teams in the 1870s. The Eureka Mine operated through World War I, when the ore was successfully processed using magnetic separation technology.

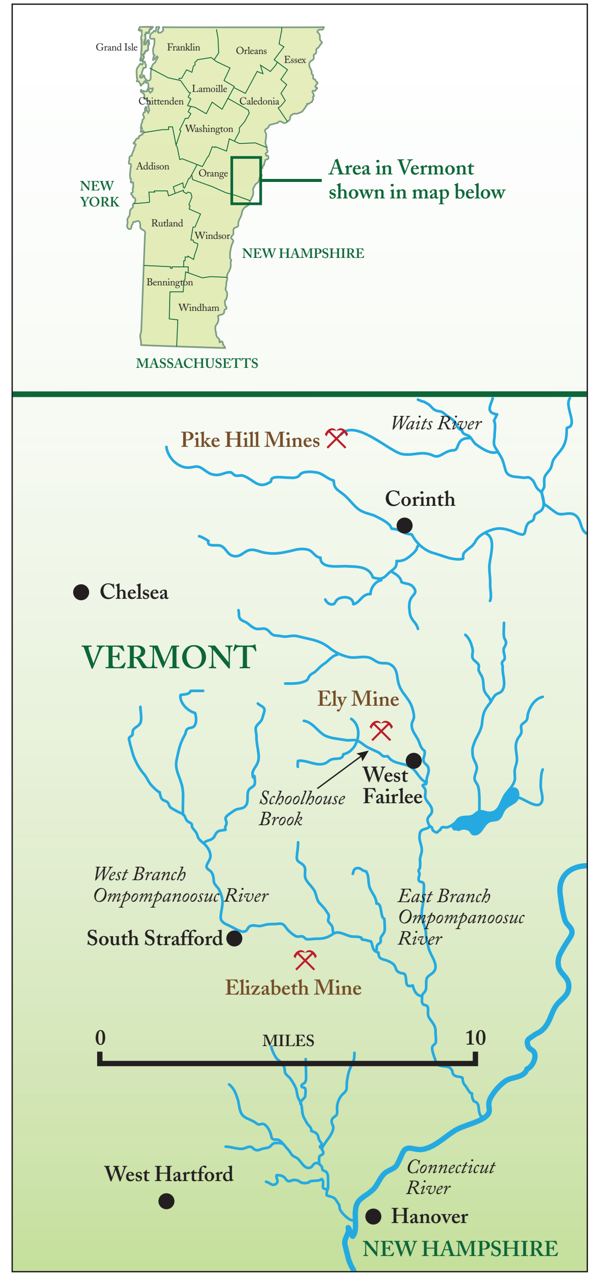
The three mines in the Vermont Copper Belt produced almost 150 million pounds of copper for the American Industrial Revolution, the Civil War, two world wars, and the Korean War. The industrial activity included technological contributions to copper processing. Mining left historically significant landscapes, buildings, and archaeological sites, as well as a legacy of environmental contamination.

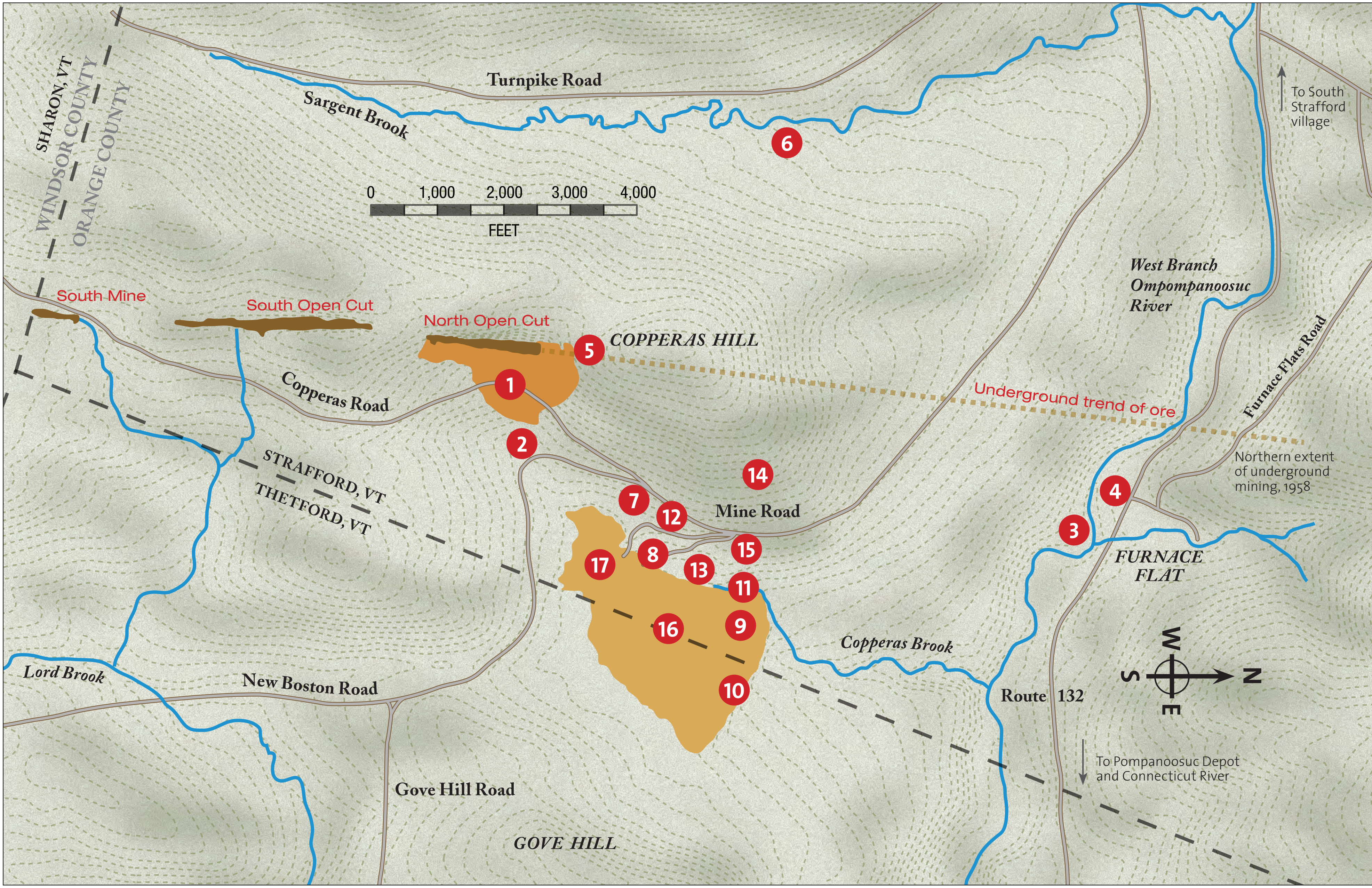
Panoramic photograph of Ely Mine village, Vershire, Vermont, about 1894. Mine workings are on the hill at center; long copper smelter building is at the right. Source: Vermont Historical Society Library.

Elizabeth Mine Site Map

The Elizabeth Mine site map on the opposite page accompanies the text on the following pages. The numbers in red circles refer to key historical activity zones or industrial landforms in chronological order of use or creation. Some early mine activity areas were later buried by the 1943–1958 tailings piles. The mine waste areas, colored orange, are shown at their maxiumum extent when mining ended in 1958. Mine-related buildings have been omitted for clarity. For additional detail and information see the site documentation drawings on pages 54 through 57.

1. Copperas manufacturing roast beds and heap leach piles, 1809–1882
2. Copperas factories location, 1809–1882
3. Vermont Mineral Factory Company copper smelting at Furnace Flat (south bank), 1829–1839
4. Copper smelting at Furnace Flat (north bank), 1854–1884
5. Tyson's Elizabeth Mining Company copper mining shafts 1 and 2, 1881–1890
6. Elizabeth Mining Company copper smelting at Sargent Brook, 1882–1884, 1888–1890
7. Elizabeth Mining Company 1898 adit, in use until 1958
8. Elizabeth Mining Company mill, used intermittently for milling copper ore, 1898–1930
9. Elizabeth Mining Company copper smelter, 1898–1902
10. Vermont Copper Corporation copper smelter, 1908–1909
11. Vermont Copper Corporation copper smelter, 1916–1919
12. Vermont Copper Company / Appalachian Sulphides Inc. support buildings complex, 1943–1958
13. Vermont Copper Company / Appalachian Sulphides Inc. copper ore processing mill, 1943–1958
14. Vermont Copper Company / Appalachian Sulphides Inc. 1948 shaft
15. Vermont Copper Company / Appalachian Sulphides Inc. 1948 adit
16. Copper ore mill tailings pile 1, 1943–1958
17. Copper ore mill tailings pile 2, 1951–1958

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Sargent Brook
SHARON, VT
WINDSOR COUNTY
ORANGE COUNTY
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FEET
To South Strafford village
West Branch Ompompanoosuc River
South Mine
South Open Cut
North Open Cut
COPPERAS HILL
Furnace Flats Road
Copperas Road
Underground trend of ore
Northern extent of underground mining, 1958
STRAFFORD, VT
THETFORD, VT
Mine Road
FURNACE FLAT
Copperas Brook
Lord Brook
New Boston Road
Route 132
W
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To Pompanoosuc Depot and Connecticut River
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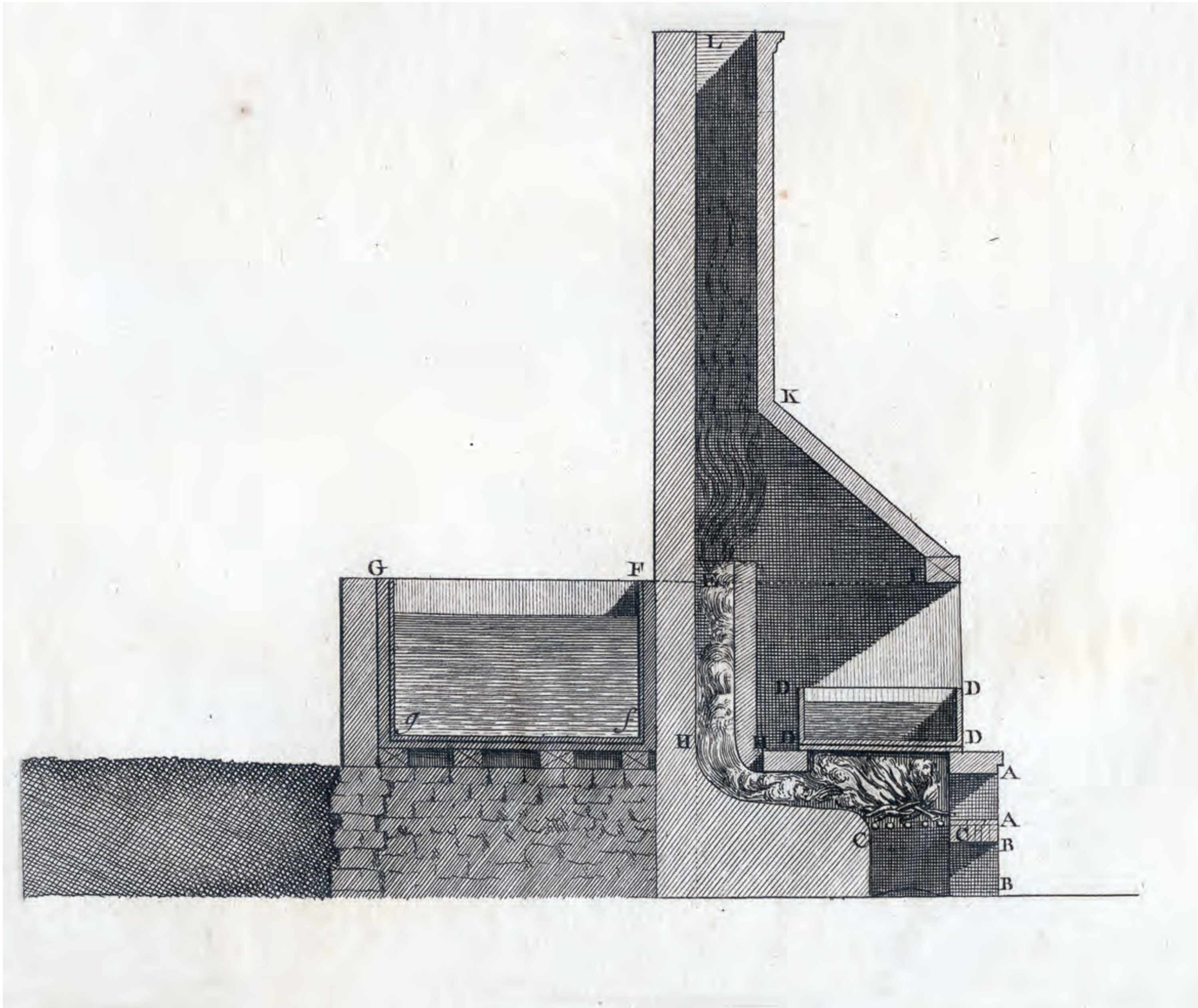


Cross section of a copperas boiling furnace from Denis Diderot's mid-eighteenth-century *Encyclopedia or a Systematic Dictionary of the Sciences, Arts and Crafts*. Copperas liquor is transferred from reservoir at left to boiling vat *D* at right. Draft from opening *B* fans fire on grate *C*, and waste heat and gases are pulled through flue *H* and up draft stack *L*. Source: Denis Diderot: *Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers*, 1751–1772.

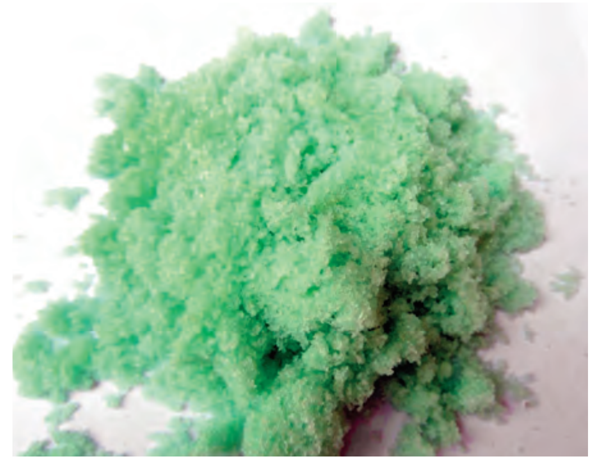
Beginnings on Copperas Hill: the Copperas Works, 1809–1882

The ore deposit on Copperas Hill in Strafford, first known as Prospect Hill, was discovered in 1793 by two men tapping sugar maples who saw rusty stains in the snow. Local mining fever spread quickly; property deeds from the time mention rights to iron ore. Outcrops of ore were soon found at locations later known as the South Mine and the North and South Open Cuts. Early miners focused on the "gossan," a shallow layer of rusty, weathered ore at the surface, believing it was a rich source of iron. A load was carted to a blast furnace at Franconia, New Hampshire, in 1809 for smelting. The high sulfur content of the ore choked the furnace, which had to be shut down. Clearly, the ore from Prospect Hill was not a viable source of iron. Once local owners recognized its iron sulfide (pyrrhotite) composition, they turned to it as a potential source of copperas, but lacked the finances and technical expertise for large-scale manufacturing.

Weak white iron sulfate (copperas) coating forming naturally on a lump of pyrrhotite (iron sulfide) ore, Elizabeth Mine, South Strafford, Vermont. Source: U.S. Environmental Protection Agency.

Copperas is an ancient name for the chemical compound iron sulfate, which usually appears as blue-green crystals or powder. Despite its name, it contains no copper. Copperas was known to ancient Middle Eastern civilizations. Its medicinal uses were known in classical antiquity, and its manufacture was described by Pliny the Elder in the first century AD. It is made by leaching iron sulfide minerals with water, boiling the fluid, cooling it, and gathering the resulting crystals. Copperas was made in several European cities by the sixteenth century. Papal controls cut off the supply to England, where the chemical was essential to the woolen industry. Copperas works sprang up in Essex and Kent in southeast England in the late sixteenth and early seventeenth centuries, creating a chemical industry that preceded the Industrial Revolution by two hundred years. By the 1760s England was one of the largest copperas producers in Europe.

A versatile chemical with many early industrial uses, copperas was used to make other chemicals, including sulfuric, nitric, and hydrochloric acids. It was particularly important in the dyeing and coloring industries, where it was used for making dyes and inks, red and brown pigments, and for blackening wood and leather. Textile manufacturers used large quantities of copperas for dyeing black cloth. It was used in agriculture to prepare soil and wash seeds and livestock to discourage pests. It was used to disinfect outhouses and sewers, preserve wood, and purify water. Copperas even had medicinal uses as a treatment for anemia and parasites.



Refined green copperas (iron sulfate) crystals. Source: http://www.hk-clkj.com

Although copperas is relatively unknown today, by the start of the nineteenth century a person could hardly go a day without encountering or wearing something made with it. In America, from colonial times, making potash, soap, salt, bleach, and dyes were small "cottage industries." But for bulk chemicals like copperas, which required capital-intensive manufacturing facilities, the colonies relied on European sources. Foreign trade was greatly curtailed during and after the Revolutionary War, forcing the new

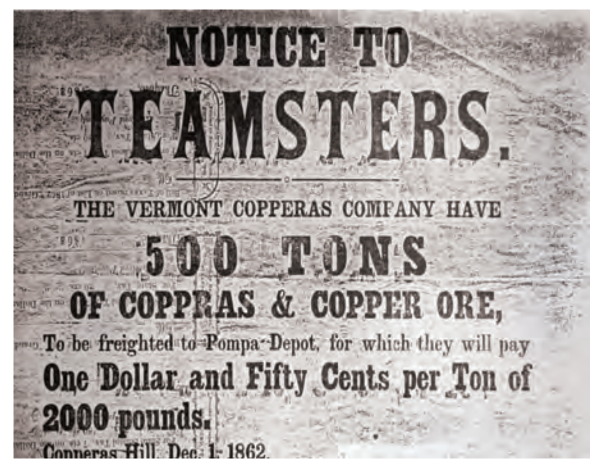
At top: President James Monroe (term in office 1817–1825) in portrait painted by Samuel F. B. Morse, 1819. Source: White House Historical Association. Above: Colonel Amos Binney Sr., Boston shipping merchant and Vermont Mineral Factory Company partner. Source: Strafford Historical Society.

states to develop their own chemical sources. Beginning in 1807, a series of embargos associated with the Napoleonic Wars continued to choke trade with the United States. By 1809, copperas was a scarce commodity in the United States.

Once Strafford's Prospect Hill was recognized as a viable source of copperas, a group of local, New Hampshire, and Boston investors consolidated ownership in 1809 and formed the Vermont Mineral Factory Company. They constructed a small copperas factory at the bottom of what soon became known as Copperas Hill, attracted skilled workers, and began production in April 1810. The pyrrhotite was mined from a pit at the top of the hill. That first year, the works produced four tons of copperas worth $1,200 that was proclaimed "as pure and of as good quality as any heretofore imported." The product was in great demand, and prices rose from four to five cents a pound to as high as sixteen cents during the War of 1812. Copperas manufacturing was considered so important that the workers were exempted from military duty.

Profitability for the Vermont Mineral Factory Company was brief, however, as foreign trade resumed after the War of 1812, and cheap copperas flooded the American market. Manufacturers petitioned the U.S. government for foreign import tariffs. The Tariff of 1816 included copperas, but even so the Vermont company was still only able to make less than 1 percent profit. In 1817, company partner and Boston shipping merchant Colonel Amos Binney Sr. persuaded newly elected President James Monroe to extend his goodwill tour of New England north past Norwich, Vermont, to tour the copperas works in Strafford. Monroe supported domestic industry, and Binney may have tried to convince him of the need for stiffer import tariffs. Not until 1824, however, was a tariff finally passed that doubled the import duty on copperas to two cents a pound, enabling the company to resume profitability. A second factory had been built in 1822, but the poor financial outlook kept production low. After the Tariff of 1824, production rose rapidly to over 1,000 tons by 1827. Colonel Binney's son, Dr. Amos Binney Jr., joined the business and in 1826 formed the Green Mountain Manufacturing Company to operate a similar, smaller copperas works in Shrewsbury, Vermont.

The Vermont Mineral Factory Company's reported annual production averaged 1,000 tons in the 1830s and 1840s, when the company declared it made 75 percent of the copperas in the United States. In 1832 the company boasted that its product was used "in every



Broadside advertising for teamsters to haul copperas to Pompanoosuc Depot, 1862. Source: Strafford Historical Society.

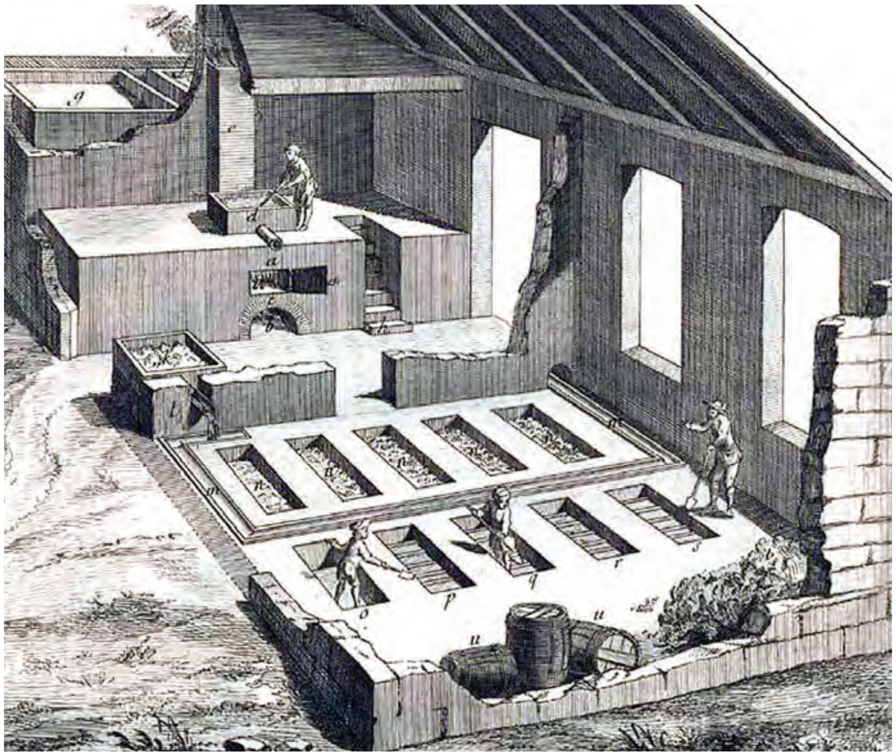
state of the Union, and almost every family, but principally by the manufacturers of woolens and cottons, hatters, and dyers." Vermont Mineral shipped its product to commission merchants William B. Reynolds & Company in Boston via turnpikes, the Merrimack River, and the Middlesex Canal from Lowell to Charlestown, Massachusetts, which had opened in 1803. From Boston, copperas was shipped to distribution warehouses in Atlantic coast and river ports including Baltimore, Richmond, and Charleston. Copperas was also shipped south on the Connecticut River to Hartford, Connecticut, and, after the completion of the Champlain Canal in 1823, west to Whitehall, New York, for shipment south to New York City via the Hudson River.

The Green Mountain Manufacturing Company's Shrewsbury, Vermont, operation closed in the wake of the financial panic of 1837, and the company merged with the Vermont Mineral Factory Company in 1839 to form the Vermont Copperas Company. The new company reportedly operated two factories on Copperas Hill, each 267 feet long by 94 feet wide, in the 1840s. Production peaked at 1,600 tons in 1844 and 1849. Construction of the Connecticut & Passumpsic Rivers Railroad in 1848 greatly improved the transportation situation for the new company, which hired teamsters to haul 500-pound and 1,000-pound casks of copperas to the Pompanoosuc Depot on the Connecticut River ten miles to the east of Strafford.

Copperas making at Copperas Hill was a simple process, relatively unchanged from depictions in historical accounts like Agricola's *De Re Metallica* of 1556 and Diderot's mid-eighteenth-century *Encyclopédie*. Iron sulfide minerals were piled up and watered, creating weak sulfuric acid and spontaneous combustion. The resulting material was leached with water, and an iron sulfate "liquor" collected. The liquor was boiled in lead-lined furnaces with scrap iron to maximize the iron content. The concentrated liquor, as strong as car battery acid, was tapped into lead-lined vats to cool and settle. It was then drained into a series of lead- or cement-lined vats where the copperas crystallized on branches, ropes, or rods, forming intricate apple-green crystals. The product was packed in heavy wooden casks for shipment, and the spent liquor was returned to the boiling vessels.

Sixteenth-century woodcut showing from top to bottom: miners roasting, leaching, and concentrating iron sulfide minerals to make copperas. *A*: furnace; *B*: enclosed space; *C*: aluminous rock; *D*: deep ladle; *E*: cauldron; *F*: launder; *G*: troughs. Source: Georgius Agricola, *De Re Metallica,* 1556. Reprinted by Dover Publications, Inc.

Copperas Hill's topography was ideally suited to this process. The ore deposit was near the top of the ridge. The bedrock on the hillside above the factories formed a large, natural sloping funnel. This allowed the operators to construct a cascading, gravity- and water-fed system with leaching heaps just below the mine, roast beds below them, and then evaporators and storage cisterns, all connected by troughs made of wood or cut into the bedrock. The boiling, cooling, and crystallizing vessels in the buildings were also arranged on stepped levels to take advantage of the flow of gravity. A testament to Yankee ingenuity, the entire gravity- and



Eighteenth-century illustration of the inside of a copperas factory showing from upper left to lower right: the outdoor storage cistern, a worker stirring the elevated boiler above an arched firebox, a movable cooling vat, multiple crystallizing vats, and wood packing barrels. Source: Denis Diderot, *Encyclopedia or a Systematic Dictionary of the Sciences, Arts and Crafts,* 1751–1772. Reprinted by Dover Publications, Inc.

Woodcut from 1844 showing the Vermont Copperas Company mine pits (a), leach heaps (c), and copperas factory (d) on Copperas Hill. Source: Charles T. Jackson, *Final Report on the Geology and Mineralogy of the State of New Hampshire,* 1844.

water-fed works operated for over 70 years without the need for any animal, water, or steam power for manufacturing.

The copperas works consumed as many as 3,000 cords of wood per year for the boilers, as well as considerable quantities of lead and iron, and gunpowder for blasting rock. The factory buildings were susceptible to exposure to the acid gases and wet soil, and had to be rebuilt several times over the life of the operation. The works required the labor of local farmers, woodsmen, coopers, and teamsters with horse-drawn wagons. A small village grew up around the factories, including dwellings, a boardinghouse, a store, a school, a cooperage, and a post office. Employment varied seasonally. From March to November the works employed about 40 to 60 men to mine ore and transport finished copperas to the Connecticut River. Inside the factory buildings, however, the gravity-fed boiling and crystallizing process required only four men. In the winter months the works employed just two

This last and most detailed description of the copperas works, adopted here in paraphrased form, appeared in Abby Maria Hemenway's 1871 *Vermont Historical Gazetteer*.

The copperas works of the New England Chemical Company may be described to consist of a prepared bed upon which the ore is burnt and leached. This bed is upon the hillside just below the vein. It is prepared by scraping the earth clean from the ledge and stopping all the fissures in the ledge with clay. The bed is nearly an acre in extent and is called the leaching ground. On the lower side of the leaching ground a trench has been dug in the ledge and is connected, by means of spouts, with four large reservoirs nearby, holding 20 hogsheads each. Still further below are two high sheds, open at the sides, with loose floors filled with brushwood called Evaporators. Upon a level spot below are the two factories of the Company. These factories contain the evaporating pans, two pans in each factory. They are made of very heavy lead 1/4 inch in thickness. Lead is the only cheap metal which is not quickly destroyed by the action of the copperas. Beneath the evaporating pans run a series of flues, commencing at the fire arches at one end of the pans and terminating in the stack at the other end. There are also two lead coolers and 20 cemented brick crystallizers in each factory. Directly beneath the crystallizers is the packing room.

The ore is blasted from the vein, wheeled to the sheds by handcars where it is broken into pieces the size of large apples; it is then shoveled into cars and run out upon the leaching ground and placed in large heaps containing from 500 to 3000 tons each. Wood is placed under the heap and set on fire. The heat of the burning wood raises the temperature of the ore, so that the sulfur is ignited, and the whole mass heated, the interior portions often red hot. Great care is exercised in burning, to prevent the heap from being overheated, as the iron of the ore would be melted and run into large solid masses and the sulfur would be driven into the atmosphere as sulfurous acid gas. To prevent this, a stream of water is applied at frequent intervals to cool the burning ore, but not enough to put out the fire. In this way a large heap will burn four months, and after it has been thoroughly drenched with water and has shown no signs of fire for six months, it will be ignited by spontaneous combustion and burn again, when it is again treated with water. The object of the burning is simply to oxidize and decompose the ore. The water upon the heated ore forms a weak sulfuric acid, which acts upon the iron of the ore and thus sulfate of iron is formed in the heaps. A heap will in a year's time become thoroughly decomposed and ready for leaching.

The leaching and evaporating has for its object conversion of the crude copperas into the beautiful green crystals. To accomplish this, a stream of water is run upon the heaps slowly to saturate the whole mass of decomposed ore. The water settles to the bottom of the heap, falls upon the prepared surface, runs into the trench below and is conducted to the reservoirs nearby. This liquor is crude sulfate of iron in a liquid state. After being allowed to settle in the reservoirs two or three days, it is conveyed in spouts to the top of the evaporators, where it is sprinkled in drops through the brush of the successive stories and a portion of the water is taken out by sun and air. The liquor will be increased in strength passing through these two sheds. From the lower evaporator the liquor passes directly to the factories where it is received in large reservoirs, whence it is drawn into the evaporating pans as needed. In these pans it is boiled down and drawn into the lead coolers and there allowed to stand in order to settle any impurities. When cool it is passed into the cemented crystallizers. Here it usually remains a week, during which time the process of crystallization takes place. The liquor is then drained off and pumped into the evaporating pans, where it mingles with the fresh liquor.

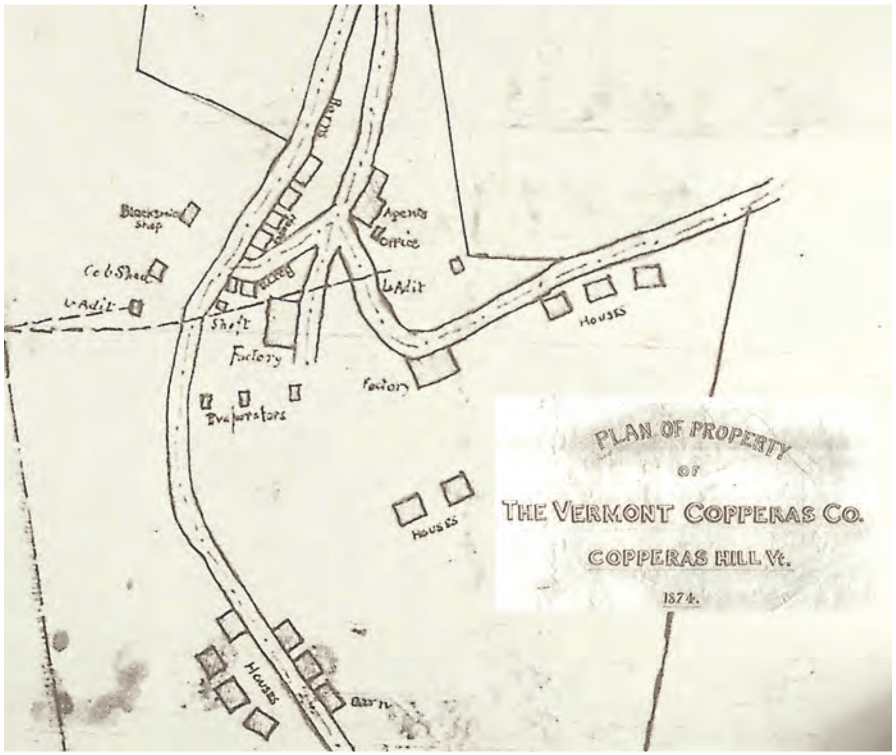
The crystals of copperas are deposited in a thick, heavy coating on the sides and bottoms of the crystallizers. The appearance of the interior after the liquor has been drained off and before the crystals have been disturbed, is extremely beautiful. The crystals are a brilliant, transparent, emerald green, assuming various forms and sizes. Some are spear-like and sharp as needles, while others assume the shape of German letters and fanciful devices. The figures formed on the bottom of the crystallizers by the grouping and arrangement of the crystals afford a beautiful and interesting study.

R.H. Duncan

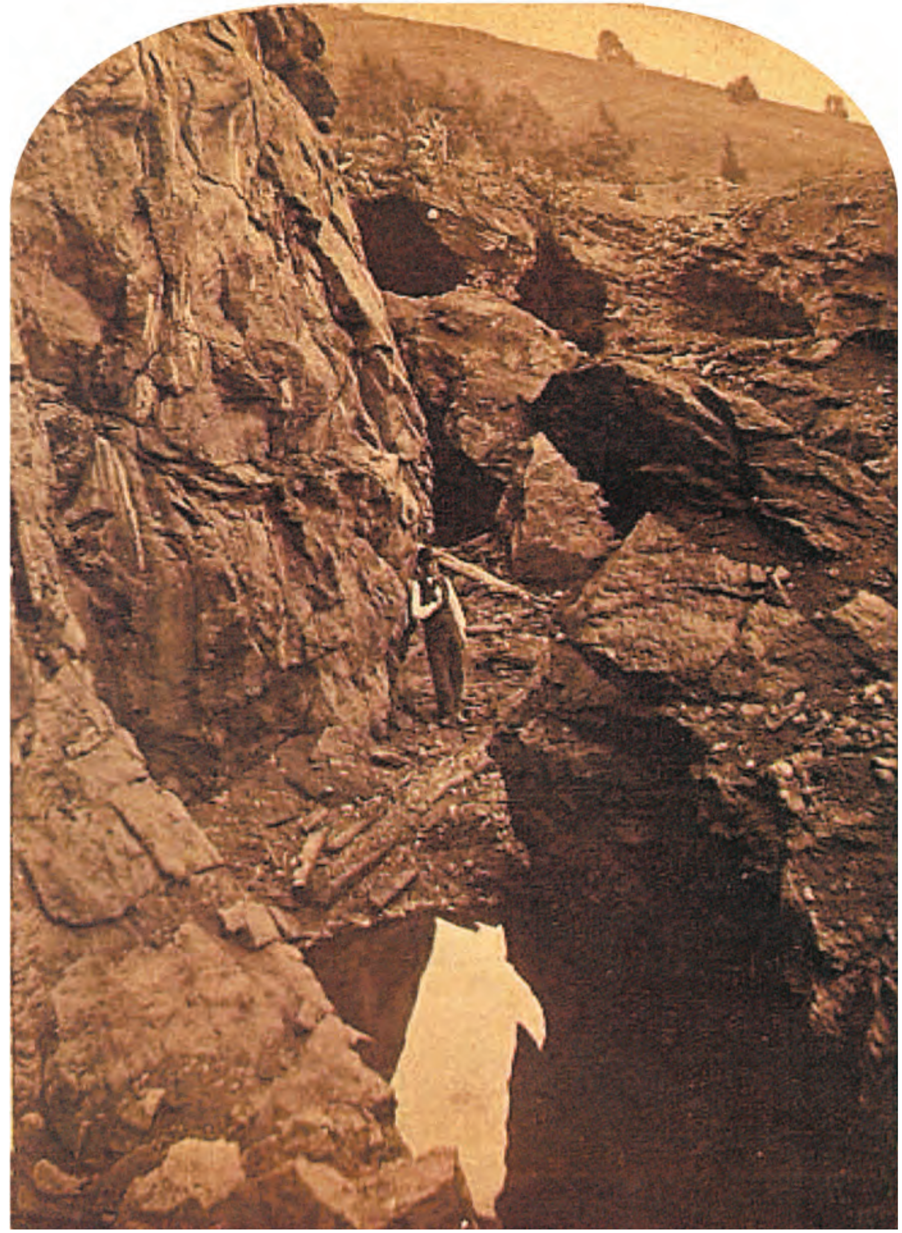
Center: Copperas crystals. Source: http://en.paperblog.com/deptford-copperas-110220/

men to repair the lead vessels. Many workers were part-time farmers who boarded at local farms or rented rooms in company-owned houses.

The Vermont Copperas Company enjoyed prosperity and productivity well into the 1850s. However, starting in 1842, import tariffs on foreign copperas were gradually lowered, and domestic demand for copperas eventually outstripped the company's production capacity. Copperas imports for the ten months preceding the April 1861 outbreak of the Civil War totaled 1,966 tons. The Vermont Copperas Company's reported output for the decade 1860 to 1870 fell to between 400 and 500 tons a year, eliminating company dividends. After the Civil War ended in 1865, the copperas



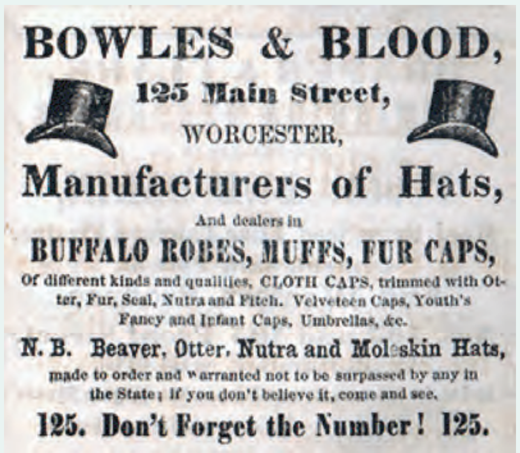
1874 map of the Vermont Copperas Company's Copperas Hill property, showing shafts, adits (tunnels), the upper and lower copperas factories, and village support buildings and worker housing. Mine Road still follows the same sharp bend today. Source: Strafford Historical Society.



Stereo card view of the North Open Cut where the copperas ore was mined, about 1870. Note the man at center for scale. Source: Strafford Historical Society.

works passed through a series of new owners, including the New England Chemical Company in 1867, a year when 1,133 tons of copperas were imported. The works passed to the New England Chemical Manufacturing Company in the 1870s. Production rose to 1,200 tons in 1878, the last year for which company records exist. In 1882 the Strafford Mining Company purchased the Copperas Hill property but soon shut down the copperas works and sold the remaining copperas stored on hand for several years after.

Fashionably Black

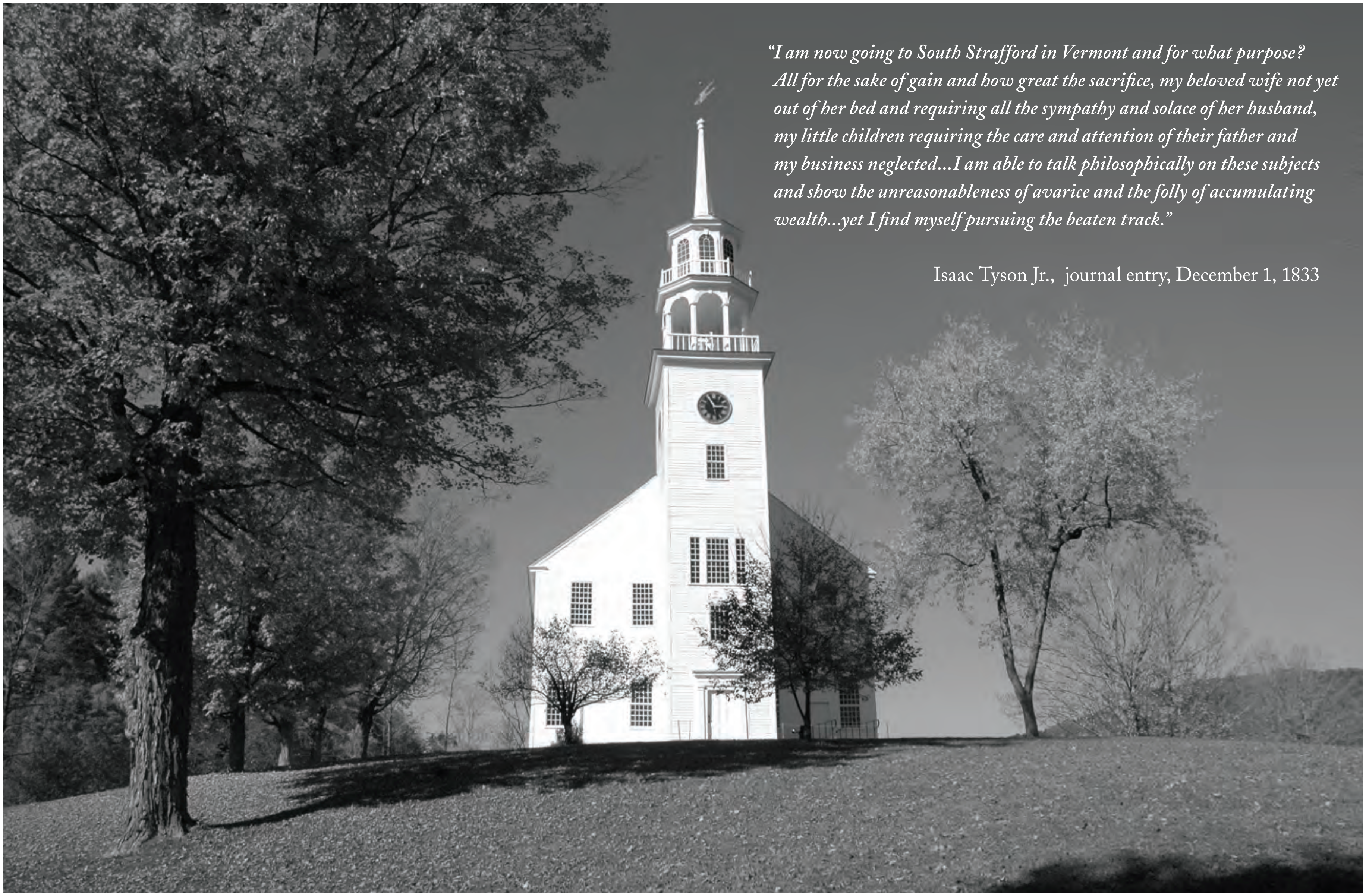

BOWLES & BLOOD,
125 Main Street,
WORCESTER,
Manufacturers of Hats,
And dealers in
BUFFALO ROBES, MUFFS, FUR CAPS,
Of different kinds and qualities, CLOTH CAPS, trimmed with Otter, Fur, Seal, Nutra and Fitch. Velveteen Caps, Youth's Fancy and Infant Caps, Umbrellas, &c.
N. B. Beaver, Otter, Nutra and Moleskin Hats, made to order and warranted not to be surpassed by any in the State; if you don't believe it, come and see.
125. Don't Forget the Number! 125.

In 1844, geologist Charles T. Jackson, reporting on the Vermont Copperas Company in the *Final Report on the Geology and Mineralogy of the State of New Hampshire*, stated that "nearly every man, who wears a black hat, or black cloth of American manufacture, is a patron of these works." Source: Worcester, Massachusetts, *City Directory,* 1835.

The South Strafford copperas operation closed for good after over seventy years of production because it had become technologically obsolete and could not compete with new sources. Large quantities of cheap copperas were a by-product of new large steel mills, where plate and wire were washed in sulfuric acid that was then boiled for copperas. By 1885, only one U.S. copperas factory, in Steubenville, Ohio, was still using natural iron pyrites. Estimates for total copperas production at South Strafford over seventy-two years total as much as 50,000 tons. Copperas manufacturing from sulfide minerals also took place at various times at locations including Ogdensburg, New York; Brookfield and Hubbardston, Massachusetts; Cape Sable, Maryland; and Pequannock, New Jersey; but those operations were all much smaller and more short-lived. The South Strafford works was by far the largest and longest-operating copperas manufacturing plant of its kind in the United States.

The 1880s saw the end of copperas making in South Strafford, but they were a time of renewal for copper mining, a story that had its beginnings in the 1820s. ▲

View on Mine Road looking west showing the ruins of the upper copperas factory with the barren roasting and leaching area on Copperas Hill beyond, 1890s. Source: Strafford Historical Society.

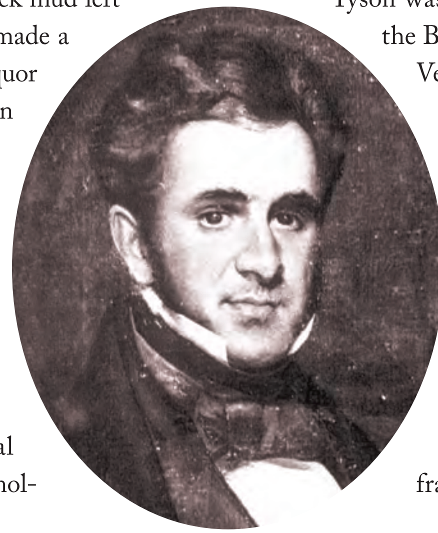


The Strafford Town House, built by local carpenters in 1799, is one of Vermont's oldest meetinghouses. Strafford's annual town meeting has been held there every year since 1801. Listed in the National Register of Historic Places, the Town House is said to be the most photographed building in Vermont. Source: Matt Kierstead.

Early Copper Smelting at Furnace Flat, 1829–1884

The Vermont Mineral Factory Company focused on making copperas during its first decade of operation, beginning in 1809. It was apparent that the copperas ore contained some copper, which was found as black mud left over in the bottom of the copperas boiling vats. The company made a small amount of "cement copper" by running weak copperas liquor from the hillside over scrap iron, which became coated with a thin layer of copper. As surface mining in the open cuts progressed down through the upper zone of weathered pyrrhotite, miners reached unweathered ore. By 1821 they realized that it contained a significant amount of chalcopyrite copper sulfide ore.

In 1827 the Vermont Mineral Factory Company decided to pursue copper production on a larger scale. This effort was championed by Dr. Amos Binney Jr. (1803–1846), who studied medicine at Harvard University but chose to go into the mining business with his father. Binney was an avid natural historian and became a nationally recognized authority on mollusk shells. The company pursued underground mining to reach fresh copper ore, and by 1831 completed a 100-foot-deep ventilation shaft and a 313-foot-long adit, or horizontal tunnel intersecting the ore from lower down the hill. The ore carts traveled on tracks laid on the floor of the tunnel, fifteen years before construction began on Vermont's first railroad, the Vermont Central.



Dr. Amos Binney Jr. Source: Strafford Historical Society.

Binney acquired land on the banks of the West Branch of the Ompompanoosuc River, about a mile north of the mine, and rights to build a dam for waterpower for a smelting plant at what became known as Furnace Flat. The Vermont Mineral Factory Company began construction on the south bank of the river around 1829. Workers built a pair of charcoal-fueled smelting furnaces, but the company lacked technical expertise to operate them properly, and sought experienced outside help. The first to arrive was Daniel Long, a skilled copper smelting man from Harford, Maryland, in 1831 or early 1832. Under Long, the works were able to produce a small amount of "matte," an impure copper metal, but the operation clearly needed additional help, as well as investment, to become truly productive.

In May 1833, the Vermont Mineral Factory Company made Isaac Tyson Jr. of Baltimore superintendant of the South Strafford copperas and copper plants. Tyson was a business partner of the Binneys, with whom he incorporated the Boston Copper Mining Company to work the South Strafford and Vershire, Vermont, copper deposits. Tyson was granted a patent for copperas manufacturing in 1827 that may have influenced practices at South Strafford.

When Tyson took over the Furnace Flat smelter in May 1833, the works included a dam, raceway, and waterwheel to power the air blast for the smelting furnaces, and kilns for making wood charcoal smelting fuel. Miners cobbed, or broke up by hammer, the ore and visually sorted it at Copperas Hill. The lean ore was used for making copperas, and rich ore, containing up to 10 percent copper, was carted north downhill to the roast beds near the smelter. Roasting prepared the ore for smelting by fracturing it and driving off some of the sulfur. The ore was smelted in four masonry-lined furnaces. The Binneys, Tyson, and other investors invested at least $25,000 constructing the smelter plant. At peak operation the mine and smelter employed as many as two hundred men, and as many as eight furnaces smelted between five and six tons of ore per day.

During the winter of 1833–1834, Tyson conducted a series of efficiency and productivity experiments. He tried different ore and matte crushing and roasting methods, fuels and fluxes, hearth configurations and linings, and air blast nozzles. In an early attempt to profit from by-products, he also experimented with making sulfur and paint from waste materials. Tyson stayed informed about technological developments in Europe and elsewhere in the United States, and visited a similar copper smelter in Simsbury, Connecticut, to compare processes.

The early 1830s was an important time for experiments and patents for anthracite coal fuel and hot air blast for metal smelting. In 1833, Frederick Geisenhainer was granted a patent for smelting the first iron in America using Pennsylvania anthracite coal, a fuel that Tyson adopted for copper smelting at Furnace Flat the following

Isaac Tyson Jr.

Isaac Tyson Jr. Source: Strafford Historical Society.

Isaac Tyson Jr. (1792–1861) was a pioneering early nineteenth-century American industrialist in the areas of mine engineering, industrial chemistry, and metallurgy. A Baltimore Quaker educated in France, he applied his scientific curiosity to mining and minerals and became involved in the copper, iron, lead, magnesite, and manganese industries. His Baltimore Chrome Works produced most of the world's chrome ore until the 1850s and supplied world markets with chromium-based chemicals and pigments for 140 years. He also developed numerous chromite, copper, and other mines in the mid-Atlantic states. After his copper smelting experiments at South Strafford, Tyson's operations included an iron furnace in Plymouth, Vermont, that ran from 1838 to 1853. Tyson was inducted into the National Mining Hall of Fame in Leadville, Colorado, in 1996.

year. The efficiency of preheating the air blast for iron smelting had been proven by James Neilson in Scotland in 1828. Tyson designed his own air preheating apparatus for Furnace Flat, and obtained a patent for the device in April 1834.

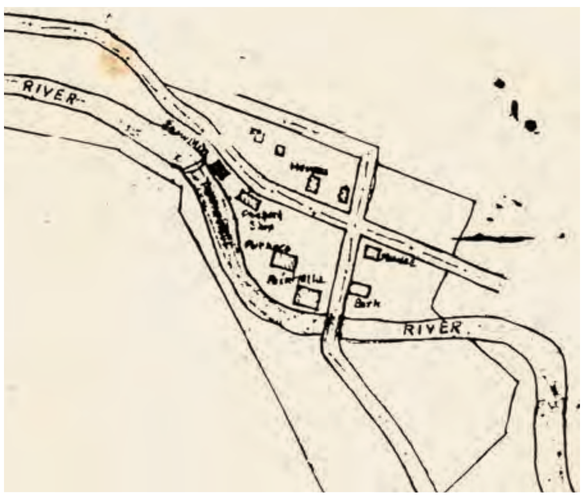
Technological advances at Furnace Flat unfortunately coincided with a financial panic, including the failure of the Bank of Maryland in March 1834. High fuel costs, poor transportation, and technical obstacles to making high-quality refined copper were chronic problems for the smelting operation. Isaac Tyson suffered from separation from his family and grappled with internal conflicts between his simple Quaker life and desire for business success. He returned to Baltimore in August 1834 convinced that the South Strafford venture was a failure. The smelting plant carried on under Daniel Long until it closed in 1839 in the wake of the Panic of 1837.

It is not known how much copper the Vermont Mineral Factory Company made over the decade the Furnace Flat smelter operated. Total combined copper production for the United States and Canada was reportedly just 50 tons in the year 1830 and 100 tons in 1840. Regardless of output, this smelting plant was an unusually early, large, and unprecedented type of operation for Vermont and the United States. Despite the remote location and transportation and fuel supply challenges, Isaac Tyson Jr. and Daniel Long succeeded in several major technological accomplishments for American copper metallurgy. These included the first U.S. use of anthracite and hot blast for copper smelting, and the first successful, large-scale, mine-side smelting of sulfide copper ores in a masonry-lined furnace. Of the nine different copper smelting campaigns conducted at different times and places at South Strafford, this was one of the two most historically and technologically significant. The first Furnace Flat smelter and Tyson and Long's accomplishments there were forerunners of the first big U.S. East Coast custom copper smelters of the 1840s in Baltimore and Boston.

In 1854, the Vermont Copperas Company built a new smelter on the north bank of the Ompompanoosuc River, west of the 1830s Tyson smelting plant. Construction of the Connecticut & Passumpsic Rivers Railroad near Strafford in 1848 made smelting more practical, as Pennsylvania anthracite fuel could be inexpensively shipped to the mine. Copper matte became easier to ship out to new East Coast smelters, including the Revere Copper Company's 1844 Point Shirley smelter in Winthrop on Boston Harbor, which Daniel Long helped operate after his stint at South Strafford. By 1860, the Vermont company was operating two furnaces and made 60 tons of copper matte that year. During the Civil War, when demand and prices for copper were high, the company operated as many as four furnaces and employed up to one hundred people, and made several shades of red paint, including a "venetian red," from waste material from the copperas plant.

The Vermont Copperas Company shut down the Furnace Flat smelter in 1867 when copper prices slumped after the end of the Civil War. The trustees formed the New England

Chemical Company and continued to make copperas and paint, and shipped pyrrhotite ore to Boston, to make sulfuric acid. In the 1870s the successor New England Chemical Manufacturing Company continued copperas manufacture under owners William H. Foster and Joseph W. Cleaveland. The company took advantage of rising copper prices in 1877 and precipitated a small amount of cement copper from copperas liquor on scrap iron. About 1884 the Strafford Mining Company built a blast furnace on the north bank at Furnace Flat and very briefly smelted copper matte on a small scale. However, it would remain for the following generation of Tysons to write the next chapter of copper production at South Strafford in the final decades of the nineteenth century. ▲

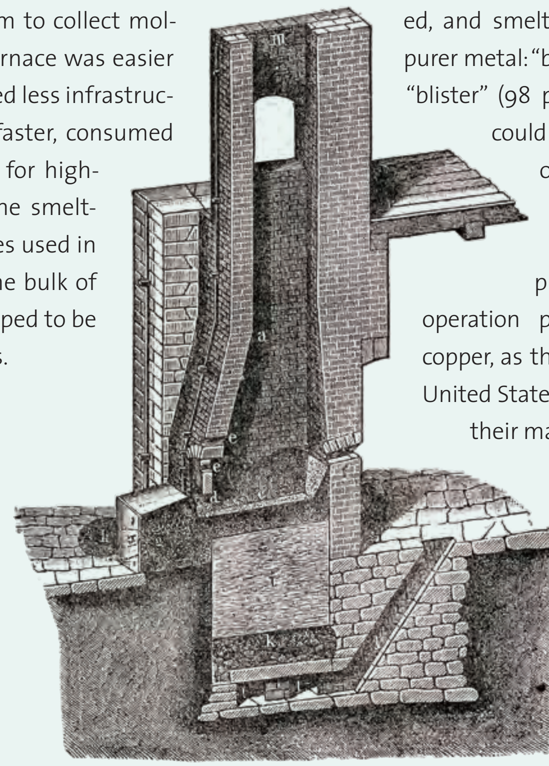


Map of the Vermont Copperas Company's Furnace Flat works, 1874, showing sawmill, cooper's shop, furnace, paint mill, barn, and worker housing. Vermont Route 132 now passes through this area. Source: Strafford Historical Society.

Copper Smelting

The early smelting furnaces at Furnace Flat were "Continental"-style "cupola" furnaces built like ones then used in Germany. They were 12- to 20-foot-high stone stacks with a heat-resistant masonry lining. They had an opening near the top for adding ore, fuel, and flux, an opening for a "tuyere," or air blast nozzle, in a 2- to 4-foot square hearth, and a clay basin at the bottom to collect molten metal. This type of furnace was easier to build and repair, required less infrastructure and labor, smelted faster, consumed less fuel, and was better for high-iron-content ores than the smelting furnaces and processes used in Swansea, Wales, where the bulk of U.S. copper ores were shipped to be smelted prior to the 1830s.

Unlike iron smelting, in which clean pig iron was made in one step, copper smelting involved several steps to remove the sulfur, iron, silica, and other impurities as slag to make metal of usable purity. The first step made an intermediate copper "matte," a semimetallic product varying widely in copper content. The matte was cooled, broken up, roasted, and smelted again in steps to make purer metal: "black" (95 percent pure) then "blister" (98 percent pure) copper, which could be cast into molds or "pigs" of impure copper. That metal still required additional molten refining to make pure copper. The 1830s Tyson operation produced only impure pig copper, as there were no smelters in the United States then that could fully refine their matte to pure copper.



Cutaway view of a typical mid-nineteenth-century masonry "Continental"-style copper-smelting blast furnace. Source: Edward Dyer Peters, *Principles of Copper Smelting*, 1907.

Elizabeth Mining Company, 1880s group portrait, including James W. Tyson Jr., second row, second from right end, with hat. Several workers hold tools of their trade including hammers, picks, and candles. Source: Strafford Historical Society.

The Tyson Years, 1880–1902

Isaac Tyson Jr. died in 1861 and left his businesses to his sons Jesse Tyson (1826–1906) and James Wood Tyson (1828–1900), both skilled in mining and mineral processing. Jesse took over the Baltimore Chrome Works, and James, who had worked at the Tysons' iron furnace at Plymouth, Vermont, became responsible for the South Strafford copper mining properties. In 1872, James Tyson purchased the remaining mining rights to the Blaisdell farm property on Copperas Hill from the Binney family, and eventually acquired about 500 acres north of the New England Chemical Manufacturing Company's copperas works.

The Tysons' Maryland copper and chrome mining businesses were in decline by the late 1870s. Copper prices, however, were on the rise, reaching 20 cents a pound in 1880, and James Tyson decided to return to Vermont for another attempt to mine and smelt copper. In 1881, Tyson incorporated the Elizabeth Mining Company, named for his wife of 30 years, Elizabeth D. Tyson (1828–1888). He acquired the former Dow farm about a mile north of the mine on Mine Road, and the brick farmhouse, renamed Buena Vista, became the Tysons' seasonal home. James Tyson, his son James Jr. (1861–1946), and their workers mined and smelted copper on and off for two decades. They did not make a large quantity of metal, but like Isaac Tyson Jr. before them, they contributed to copper smelting technology.

The New England Chemical Manufacturing Company did not allow the Elizabeth Mining Company to use the existing shafts and adits on its property to access the underground workings. The Tysons developed their own mine entrances north of the North Open Cut, which had been excavated into a long open trench. The Tysons' mining "captain," John Vial, originally from Cornwall, England, came from Maryland to oversee setting up the mine. Vial was one of many Cornishmen whose renowned mining expertise contributed to the success of early mines in Vermont and throughout the United States. Vial and his miners sunk two new vertical shafts down to reach the ore body. Shaft No. 1 was 160 feet deep and surrounded by a cluster of buildings that housed the boiler and steam engine for the hoist for raising ore and transporting miners. Shaft No. 2 was located just north and was powered by a horse whim, a primitive type of hoist in which a horse walks in a circle, turning a drum to raise and lower a cable extending down into the mine. The ore was broken up in a steam-powered mechanical jaw crusher and hauled to a new smelting plant on Sargent Brook at the west foot of Copperas Hill.

Photograph of James Wood Tyson (1828–1900), Isaac Tyson Jr.'s son. Source: Webb L. Nimick Collection.

Photograph of Elizabeth D. Tyson (1828–1888), for whom the Elizabeth Mine was named. Source: Webb L. Nimick Collection.

Buena Vista, the Tysons' seasonal home, which still stands on Mine Road near the Elizabeth Mine. Source: Webb L. Nimick Collection.

The ore was roasted in heaps for 11 weeks before smelting in a 40-ton-per-day blast furnace with a water-cooled firebrick lining. Instead of wood charcoal or anthracite coal, the smelting fuel was coked bituminous coal from western Pennsylvania. This was the first steam-powered smelting operation at the Elizabeth Mine. Between 1882 and 1884 the furnace made a 20 percent copper matte that was shipped to the Orford Copper & Sulfur Co., in Bergenport, New Jersey, for refining. The Tysons also refined a small amount of pig copper on site and sent it to Birmingham, England, for making brass pins. Metallurgist William Glenn, a former Confederate colonel and military engineer from Norfolk, Virginia, oversaw the smelter plant. Glenn consulted with William Long, son of Daniel, who had helped Isaac Tyson Jr. at Furnace Flat and who was in charge of the massive smelter plant at the Ely Mine in nearby Vershire. Glenn conducted the first known American copper smelting experiments with chromite furnace linings, documented the efficiency of the water-cooled hearth, and developed more efficient ways of charging raw materials into the furnace.

Copper prices fell in 1884, and the Tysons shut down the South Strafford operations. In 1886 Boston metallurgist Henry M. Howe visited and recommended improvements, including a new adit farther north at the base of Copperas Hill to reach deeper ore reserves, and new types of furnaces to make higher grades of copper matte. The mining company did not have the funds to make those improvements. Copper prices rose to 17 cents a pound by 1888, and the Tysons resumed mining and smelting a 40 percent copper matte they sold to the American Metal Company of New York for refining. The operation employed 25 to 30 workers. The Tysons were considered good employers, and worker relations were peaceful, in contrast to those at the nearby Ely Mine, where the National Guard was called out to quell a labor revolt in the infamous 1883 "Ely War." Transportation costs were still an issue, as it cost three times as much to transport materials ten miles between the mine and the Pompanoosuc Depot by horse as it did from the depot to Boston or New York City by train. Metal prices slumped after the repeal of the Sherman Silver Act in 1890, and the Tysons ceased operations again.

The Tysons took advantage of downtime during the poor economy of the early 1890s and followed Henry Howe's recommendations, investing in new facilities at a new location northeast of Copperas

Miners pose outside the cluster of buildings above the No. 1 shaft on Copperas Hill, 1880s. These buildings housed the steam engine, hoist, and ore crusher. Source: Collamer Abbott Collection, University of Vermont.

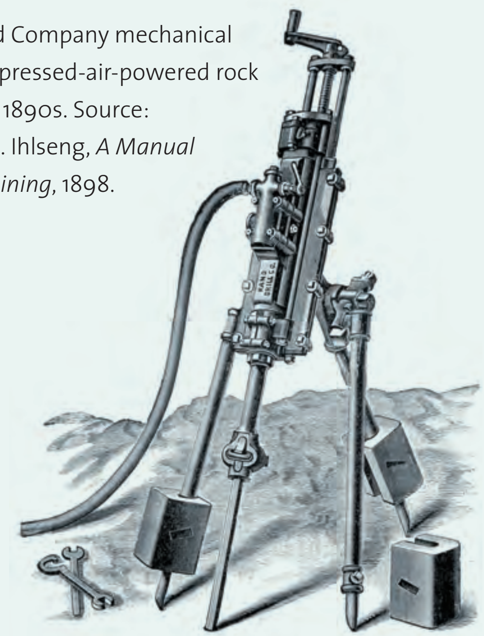
Photograph of James W. Tyson Jr. (1861–1946). Source: Webb L. Nimick Collection.

Hill. Between 1895 and 1898, miners excavated a 1,400-foot-long adit to intersect the ore body, north of their previous shafts. Excavation of the 1898 adit began with hand drills and black powder, and was completed with Sullivan compressed-air-powered mechanical rock drills. By the time it was completed, copper prices peaked at 19 cents a pound because of increased demand from the burgeoning electrical industry and artificially high prices set by the dominant Amalgamated Copper Company. The Elizabeth Mining Company sold high-grade ore containing more than 10 percent copper to the Mountain Copper Company smelter in New Jersey to generate

Drilling and Explosives

Before mechanical rock drills became available in the 1870s, miners drilled holes in rock to place explosive blasting charges by hand. Two or three miners would take turns holding a long steel drill bit and hitting it with sledgehammers, a hazardous practice known as double or triple "jacking," after "Cousin Jacks," the name given to Cornish miners, who often worked in small family teams. In 1871 Simon Ingersoll and the Rand Brothers introduced the first mechanical rock drills—heavy, awkward machines powered by steam. They were soon replaced by compressed-air-powered drills, which generated rock dust that gave miners the lung disease silicosis, or "miners' consumption." Later drills included water jets to reduce dust, and were smaller and lighter. Mechanical drilling greatly increased mine productivity and swept through the mining industry, replacing hand drilling by World War I. Developments in explosives kept pace. Miners blasted rock with simple black powder until the 1860s, when Alfred Nobel developed the first high-explosive "dynamite" using nitroglycerine, which was popular until about 1910. Nobel also developed gelatin and ammonium nitrate explosives, which replaced nitroglycerine.

Miners using a manual drill and sledgehammers to bore a hole in rock. Source: International Correspondence Schools, 1907.



Rand Company mechanical compressed-air-powered rock drill, 1890s. Source: M. C. Ihlseng, *A Manual of Mining*, 1898.

operating cash. The Elizabeth Mining Company built a new ore-processing mill with a mechanical crusher and equipment for gravity separation of ore and waste rock. North of the mill they built an ore-roasting complex fed by railroad tracks on two parallel levels for gravity handling of ore. The tracks extended farther north to a new smelter plant housed in a series of connected sheds on the hillside. The smelting furnaces included a 150-ton-per-day, rectangular hearth blast furnace to make copper matte, a 40-ton-per-day furnace to refine the matte, and a 10-ton-per-day horizontal "reverberatory" furnace to make partially refined pig copper. The product was sold to the Bridgeport (Connecticut) Brass Company and refined at the Nichols Chemical Company on Long Island, New York. James Tyson Jr. took over full-time management from his father and ran the works, which employed 84 men, from Buena Vista.

Unfortunately, despite the new adit, mill, and smelter, the operation was not profitable. The Tysons paid off the mine property mortgage in 1899, just as the price of copper began to fall again. James Tyson Sr. died in 1900, and James Jr. was appointed receiver for the mine. The company was cash-short and behind on its payments to creditors, and fuel shortages and transportation difficulties continued to plague the operation. Stockholders, mostly Tyson family members, tried to sell the mine for cash, and even turned down a $600,000 offer from George Westinghouse, who instead purchased the Ely Mine to conduct his smelting furnace experiments. Mining and smelting continued until June 1902, when the Elizabeth Mining Company ceased operations for the last time.

Despite the circumstances, the Tysons and William Glenn made important innovations in copper smelting practice. They successfully experimented with chromite ore linings in their furnaces, extending the life of the linings and reducing the time needed to

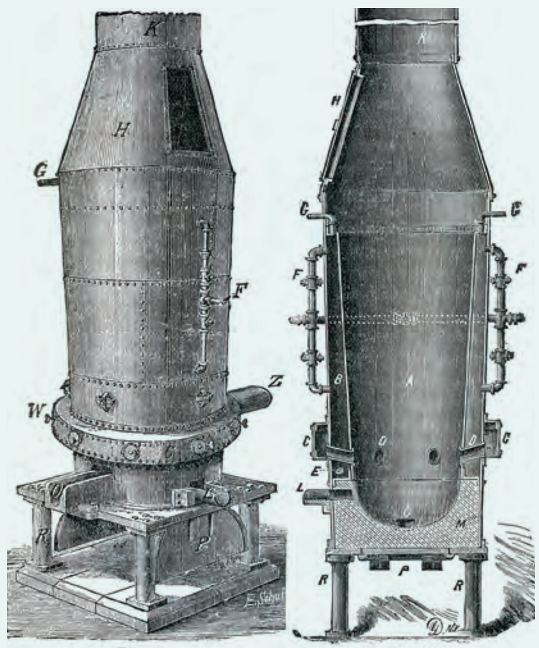
Tyson mill and roast beds, about 1900. The mine railroad trestle was used for delivering ore to roast beds. Sulfur fumes can be seen rising from roasting ore. Source: Collamer Abbott Collection, University of Vermont.

Tyson smelter, about 1902. The plant was built into the hillside to take advantage of gravity for moving materials. Source: Collamer Abbott Collection, University of Vermont.

Advances in Copper Smelting

By the 1880s, vertical, cupola-type copper and iron smelting furnaces were being built larger, with cylindrical interiors and multiple air nozzles, resulting in the term "blast" furnaces. Horizontal reverberatory-type furnaces, first commonly used for copper smelting and refining in England, came into greater use for refining in America. Unlike a blast furnace, where the fuel is in direct contact with the charge, in a reverberatory furnace, fuel and charge are separated, and hot combustion gases pass under an arched hearth which reflects heat down onto the molten metal. All types of smelting furnaces were built bigger to process more ore, but also included other advances to increase efficiency.

One important advance was water-cooling jackets—metal plates enclosing furnace hearths and filled with circulating water. These kept masonry furnace linings cooler and made them last much longer, reducing brick consumption and downtime for furnace relining. Another area of advancement was refractories—heat- and chemical-resistant lining materials. Most furnaces were lined with silica firebricks, which rapidly eroded from the molten iron and silica in slag. These chemically "acid" refractory materials were replaced by longer-lasting "basic" refractories such as chromite and magnesite. The combination of water cooling and basic linings dramatically increased the length of furnace campaigns. Success with these practices led to the development of the Peirce-Smith copper converter, which reduced the number of intermediate refining steps previously required to refine copper matte to pig copper. At the Elizabeth Mine, James Tyson and William Glenn were able to increase the length of their blast furnace campaign from one week to more than twenty-six with water cooling and chromite refractory linings, the first successful use of chromite copper smelter linings in America.



Typical water-jacketed copper smelting blast furnace of the 1880s. The external pipes circulated cooling water around the hearth. Source: Edward Dyer Peters, *Modern Copper Smelting*, 1905.

shut down to replace them. This practice was widely adopted by the copper smelting industry. Tyson and Glenn also devised a way to skip the intermediate refining process and tap molten matte directly from their blast furnace to the reverberatory furnace. They converted it to "blister" copper with a blast of hot air, steam, and sand, making pig copper in two steps instead of three. They were unable to get a patent for their "reactor" process, however, though a similar practice was ultimately adopted by the copper industry. Another chapter in Strafford mining history had ended, but the story was still far from over.

An 1899 sketch of miners working underground at the Elizabeth Mine. Source: The *United Opinion*, Bradford, Vermont, December 15, 1899.

Early Miners

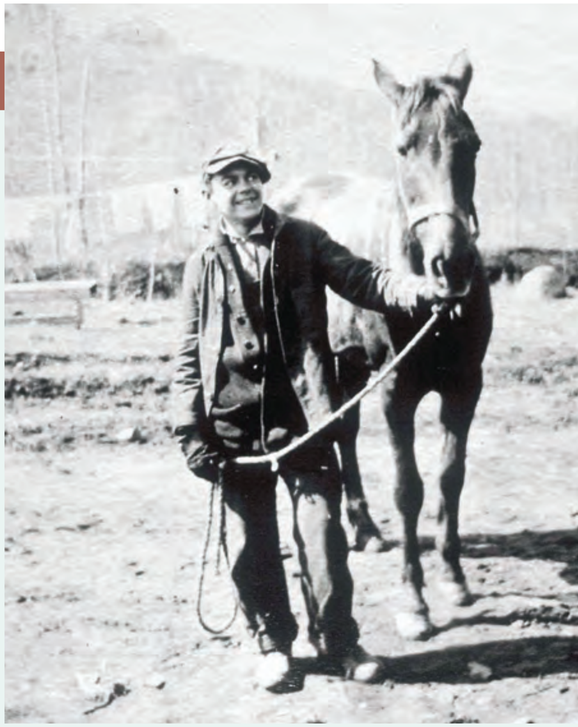
The history of Vermont's Orange County's mining companies and their leadership and technological innovations overshadows the history of the miners and laborers who literally did the heavy lifting. South Strafford's miners came from near and far. Many were local farmers who took on seasonal employment, or itinerant career miners from up and down the Appalachians or overseas. One 1830s account states that of the 25 to 30 workers at Copperas Hill, there were "five Yankees, one Welsh, the rest Pats [Irish]." Of the 84 men working for the Tysons in 1900, 34 were Vermont natives, and the rest were from Germany, Ireland, Poland, or Scotland.

Nineteenth-century records for mining employment at South Strafford are incomplete,

A group of miners pose underground at the Elizabeth Mine around World War I. Source: Strafford Historical Society.

Early miner's canvas cap with carbide lamp worn at the Elizabeth Mine. Source: Strafford Historical Society.

A team of eight horses hauling a steam boiler to the Elizabeth Mine from the railroad at Sharon, Vermont, about 1890. Source: Strafford Historical Society.



An Elizabeth Mine teamster and his horse, about 1900.
Source: Strafford Historical Society.

but employment appears to have been variable and seasonal. Vermont Mineral Factory Company accounts indicate 75 workers in 1831, but some of those may have been at the company's Shrewsbury, Vermont, copperas works. An early 1830s Copperas Hill store ledger entry recorded 210 men working on the hill in August. The same ledger notes that there were no workers on the hill by late November, likely because the ground was frozen and the copperas process depended on flowing water. Isaac Tyson Jr.'s journal for that time mentions 80 men on the hill mining copper ore for smelting at Furnace Flat. The U.S. Census of Mines, Agriculture, Commerce, and Manufacturing listed 8 employees at the copperas works in 1840, 15 in 1850, 45 in 1860, 7 in 1870, and 30 in 1880, when two-thirds of workers were under the age of 16. The Tysons reported that there were 25 to 30 employees during their 1880s copper mining and smelting campaign, and 84 during their late 1890s operations.

Some miners who lived or farmed nearby walked or rode horses between home and work. The itinerant and immigrant workers boarded with farmers or lived close to the mine in company-supplied housing. Miners with families lived in single or duplex dwellings, and bachelors lived in boardinghouses. Rent for company housing was deducted from wages. Liquor was not allowed on company property, but that did not stop miners from visiting local taverns, and men found inebriated at work were dismissed and forfeited any wages due. Company papers include records of "runaways"—miners who left the property without settling debts.

The mining companies benefited from copperas and copper profits far more than the surrounding community, but town and firm still depended on one another. The mine workers needed food and goods, and their neighbors needed their business. Mine operators relied on local services, including coopers to make shipping barrels and casks and teamsters to ship copperas and copper matte to the railroad at Pompanoosuc. Local blacksmiths repaired mining machinery, sharpened drills, and shoed horses. During the 1830s, Justin Morrill ran a store at Copperas Hill that carried necessities and luxury items such as sugar, nuts, raisins, oranges, and tobacco. A post office operated at Copperas Hill from 1853 to 1888.

Most of the miners' food was provided by the mining companies, which operated their own farm for most of the nineteenth century. The Vermont Mineral Factory Company hired Benjamin Preston Jr. to run the farm for three years in 1828. The contract between Amos Binney Sr. and Preston stipulated that Preston had to purchase all livestock, stores, and household goods, make improvements, and board mine employees. Preston could sell all meat and produce to the miners and charge $1.25 a week for rent. In 1888 the 300-acre farm was run by George W. Roberts, and included a boardinghouse for 50 men, a barn, shed, and stable.

A late nineteenth-century portrait of a group of South Strafford miners of various nationalities dressed for a special occasion. Source: Collamer Abbott Collection, University of Vermont Libraries, Special Collections.

August Heckscher's Vermont Copper Corporation smelting plant about 1908. Ore was transported over the trestle at right and across to the smelter at left. Flue and chimney were for dispersing smelter fumes. Ore roast beds from the Tyson family's previous Elizabeth Mining Company smelting operation are in foreground. Source: Strafford Historical Society.

Early Twentieth-Century Ventures, 1904–1931

At the start of the twentieth century, growing demand for copper from new electrical communication and power industries coincided with depletion of many rich copper ore deposits in the United States. Engineers and scientists developed new technology to yield copper and other metals from leaner ores. New mechanical equipment, electrical power, and mass-production techniques saved fuel and labor, and made possible efficient and profitable mining and processing of large, low-grade ore deposits.

In this period, several Orange County, Vermont, copper mining ventures incorporated new technology, including magnetic separation, pyritic smelting, and froth flotation. None of these Vermont trials were innovative or unique, and not all were successful. They were simply another round of efforts to make the Vermont "Copper Belt" mines pay. The technology may have been new, but the reasons for failure were familiar: the wavering national economy, fluctuating copper prices, poor funding, expensive transportation, complex geology, and dramatic accidents.

Vermont Copper Corporation blast furnace under construction, about 1908. The main air blast pipe and row of individual blast nozzles are visible above the detachable hearth. Source: Strafford Historical Society.

After the Elizabeth Mining Company left in 1902, John H. Judson and Lewis G. Rowand of New York leased the mine from the Tyson receivers. They had been involved in development of an electromagnetic ore separator for the Wetherill Separating Company. Magnetic separation was an old idea that had been used successfully in iron ore enrichment as far back as the early nineteenth century, and as nearby as the Franconia, New Hampshire, iron furnace. Once commercial electricity became available, the process became more powerful, practical, and popular.

Judson and Rowand tried unsuccessfully to persuade the American Metal Company, a worldwide investor in copper properties, to invest in a pilot electromagnetic separation plant at the Elizabeth Mine. They succeeded in getting the New Jersey Zinc Company, which used Wetherill separators, to invest in the venture. In 1904, Judson and Rowand installed their new equipment in the Tysons' 1890s ore mill, where they ground the ore to a fine powder, roasted it to magnetize the unwanted pyrrhotite, and ran it through electromagnets to separate out the copper-bearing chalcopyrite. The process, which had worked in their laboratory, failed at an industrial scale because the ore would not magnetize properly. This process was later used successfully by others at the Pike Hill mines in Corinth between 1907 and 1909.

In 1906, former New Jersey Zinc Company general manager August Heckscher (1848–1941) purchased the Elizabeth Mine for $200,000. Heckscher consolidated all mine landholdings under the Vermont Copper Corporation and made James W. Tyson Jr. superintendent. Heckscher brought the Tysons' old gravity ore-separation equipment back on line and built an extensive system of elevated timber trestles for moving ore cars from the mill to a new, elaborate and expensive smelter plant located several hundred feet farther east in the Copperas Brook valley. The new blast furnace was designed to smelt 300 tons of ore per day using a "semi-pyritic" process, burning a portion of the sulfur in the ore as a partial fuel source. Smelter fumes, which contained sulfur dioxide, were vented uphill in a 400-foot-long brick arched flue to a 125-foot-tall brick chimney. The entire operation was powered by electricity from Heckscher's Sharon Power Company, which included a new dam and power plant several miles south of the mine on the White River below the village of Sharon. Smelting began in late 1908,

Vermont Copper Corporation brick-arch smelter smoke flue under construction, about 1908. Source: Strafford Historical Society.

but the wood-framed furnace building caught fire the following February from a splatter of molten metal. Heckscher promptly rebuilt the shed that summer using steel, only to have about 100 feet of the smoke flue destroyed in an explosion that fall. Heckscher gave up smelting but did conduct extensive exploratory rock core drilling to confirm the true size of the copper ore deposit, which proved to be over two miles long, 300 to 600 feet tall, anywhere from 12 to 64 feet wide, and contained an average of 2 percent copper. The ore was, however, hard to mine and upgrade, and remote from transportation.

Demand for copper during World War I drove copper prices up again, and the Vermont Copper Corporation resumed mining and smelting in 1916. Heckscher hired the General Engineering Company to replace the antiquated gravity ore-separation machinery with new froth flotation equipment to separate the chalcopyrite from the waste rock. A new semi-pyritic blast furnace made about 350,000 pounds of copper matte. Although Heckscher's operation used state-of-the-art power generation, materials handling, ore milling, smelting, and smoke-dispersion technology, it only lasted as long as copper prices were inflated by war. Prices fell again in 1919, and Heckscher decided to abandon smelting because of fuel and flux

Sharon Power Company dam on White River in Sharon, Vermont, about 1908. August Heckscher's Vermont Copper Corporation was the first operation at the mine to be powered by electricity. Courtesy of Dartmouth College Library.

Vermont Copper Corporation smelter chimney under construction, about 1908. The chimney was intended to disperse smelter fumes in the valley. Source: Strafford Historical Society.

August Heckscher

August Heckscher was born in Hamburg, Germany in 1848 and emigrated to America to mine anthracite coal with relatives in Shenandoah, Pennsylvania. His interest turned to zinc and in 1881 he founded the Lehigh Zinc and Iron Company. He was instrumental in organizing the 1897 "Great Consolidation" of mines in the Franklin-Ogdensburg, New Jersey district into the New Jersey Zinc Company. This led to modernization of the district, known for its unusual geology and complex ore separation problems, and NJ Zinc became one of the top zinc producers in the United States. Heckscher resigned as NJ Zinc's General Manager in 1904 to pursue projects including reinvigorating the Elizabeth Mine. He later devoted attention to charities and philanthropy, donating money for parks in New York City and Huntington, Long Island. He endowed the Heckscher Foundation for Children in 1899, and built the Heckscher Museum of Art in Huntington in 1920. He died in Florida in 1941.

Detail from 1925 portrait painting of August Heckscher by Penrhyn Stanlaw. Used with permission of the Heckscher Museum, Huntington, New York.

shipping costs, and concerns from a neighbor over possible smelter fume impacts to his farm.

The ill-fated production attempts and fluctuating copper prices of the opening decades of the twentieth century made the outlook for the Elizabeth Mine bleak. In 1925 the American Metal Company took brief interest in the Elizabeth Mine and over the course of six months made 1,756 tons of 18 percent copper concentrate it shipped to Carteret, New Jersey, for smelting.

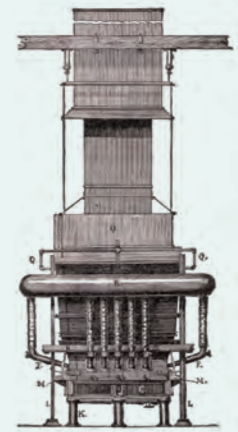
The last attempt to work the Elizabeth Mine before the onset of the Great Depression was championed by Frederick W. Foote, a mining engineer experienced in sulfide ores and convinced the mine could pay. Foote formed the National Copper Corporation in 1928 with the old idea of extracting additional products from the ore, including iron and sulfur. National Copper reequipped the old Tyson mill and made 6,330 tons of copper ore concentrates before closing the plant in 1930 because of falling copper prices. In its final months, the updated flotation equipment reached its predicted output of 300 to 350 tons per day of 20 percent copper concentrate, recovering more than 90 percent of the copper in the ore. Experiments proved that the iron- and sulfur-bearing pyrrhotite could also be separated. In 1931, Foote proposed construction of a 500-ton-per-day mill, and sulfuric acid production. Exploratory drilling revealed enough copper ore reserves for ten years of operation. Foote's lease expired, but he maintained an option on the property and waited for market conditions to change.

Lack of accurate production information makes it difficult to determine the total quantity of refined copper made from Elizabeth Mine ore over the century between 1830 and 1930. The amount appears to stand between 10 million and 19.2 million pounds. This is less than the estimated 30 to 40 million pounds of copper metal from the Ely Mine in Vershire, and far more than mined from the Pike Hill mines in Corinth.

The early twentieth-century efforts at the Elizabeth Mine did not yield much copper. But the work did confirm that large reserves of ore remained to be mined and that the copper could be efficiently separated by froth flotation. The Elizabeth Mine's potential viability had been proven, but it lay dormant, waiting for the most powerful driver of mining and metallurgy—war—to bring it back to life. ▲

Early Twentieth-Century Ore Milling and Smelting Technology

The development of froth flotation ore separation is considered the birth of the modern mining industry. Earlier mechanical ore separation exploited differences in specific gravity between finely ground ore and gangue (waste rock). As early as 1860, mine operators had noticed that certain mineral particles stuck to oils. A series of processes based on that phenomenon was developed in the late 1800s, ending with the first commercial froth flotation plant, built in Broken Hill, Australia, in 1905. Froth flotation relies on the attraction of fine particles of metallic ore to chemically treated bubbles. In this process, ore is ground to a fine consistency by tumbling it in water-filled drums with steel balls or rods. The resulting slurry is added to tubs filled with water, pine oil, and other chemicals and agitated with motorized paddles and rising bubbles. Metallic ore particles are attracted by the surface tension of the floating bubbles, which are skimmed off, and the concentrate is dried for smelting. The fine waste rock powder falls to the bottom and is pumped to a tailings storage area. The first commercial froth flotation mill in the United States was installed at the Black Rock Mine at Butte, Montana, in 1912. In 1914, three years before flotation started at the Elizabeth Mine, there were forty-two flotation mills operating in the United States. The process was also used briefly on a small scale at the Ely and Pike Hill mines in the World War I era.



Blast furnaces also continued to evolve, becoming bigger, with long, rectangular hearths and multiple air nozzles. These furnaces were designed for "pyritic" or "semi-pyritic" smelting, which burned the sulfur in the ore, replacing or augmenting conventional coke fuel. This technique eliminated open-air ore roasting, a slow process that released clouds of sulfur dioxide gas, damaging plant life around smelters. Complementary technology was developed to capture the gas and convert it to marketable sulfuric acid.

Typical rectangular-hearth copper smelting blast furnace of the early 1900s. The multiple air pipes directed air blast into the hearth at bottom. Source: Edward Dyer Peters, *Modern Copper Smelting*, 1905.

Panoramic 1940s winter view of the Vermont Copper Company's World War II Elizabeth Mine plant looking west, showing, from left to right: miners' change house, air compressor building, machine shop, office/warehouse, and the mill complex including garage, ore storage bin, flotation mill, thickener/dryer building, and crusher. The water tank building and 1948 shaft hoist house and head frame are on the hill at center, and the infirmary and clubhouse at the extreme right. The gently sloping mill tailings pile fills the valley in the foreground. For additional information see documentation drawings on pages 54 through 57. Source: Strafford Historical Society.

Copper for War and Peace, 1942–1958

The buildup to World War II in late 1938 gave the U.S. economy a boost, and as war-related manufacturing increased, so did the demand and price for metals. Commercial interest in the Elizabeth Mine as a potential source of strategic copper grew in 1940 and took off after U.S. entry into the war. After Pearl Harbor in December 1941, U.S. copper reserves were down to just one month's supply. Vermont-born lawyer and financier George Adams Ellis organized the Vermont Copper Company Inc. (not to be confused with August Heckscher's earlier Vermont Copper Corporation) in April 1942 with help from the Vermont War Production Board and former Vermont governor Stanley C. Wilson. The new company obtained mining rights for the Elizabeth, Ely, and Pike Hill mines and hired geologist Frederick Foote as a consultant. U.S. Bureau of Mines rock core drilling tests at the Elizabeth Mine indicated that 16.5 million pounds of copper could be produced within three years.

The Vermont Copper Company gathered $2.3 million in private investments and U.S. government loans to reopen the Elizabeth Mine. By May 1942, two hundred miners and laborers, including some state prisoners, were busy rebuilding the mine. They pumped and cleared out the underground passages, and enlarged the 1898 Tyson adit for an electric mine railroad to haul ore out to a new processing mill. A 7-mile-long high-tension line was built to bring electricity to the mine from Union Village. Underground, a room was blasted out at the west end of the adit, called the 300-foot level, where a 250-horsepower hoist was installed to pull mine cars up an 800-foot-long winze, or inclined shaft, that led north down to the 600-foot level. Most of the old Tyson-era buildings were demolished and replaced with a new surface plant consisting of a change house for miners to dress for work underground, a compressor building to supply air for the rock drills, and support buildings, including a machine shop, warehouse, and office. The mine railroad was extended to a new, 500-ton-per-day flotation mill installed by the Galigher Company of Salt Lake City, Utah, and built into the hillside to take advantage of the flow of water and gravity. Other buildings included a heat plant, a garage, a laboratory, a water tank, and an infirmary. The Federal Housing Authority built a cluster of dormitories and a recreation building for new miners and their families, and a company boardinghouse included a kitchen for the miners to congregate and have hot meals.

The U.S. Reconstruction Finance Corporation's Metals Reserve Corporation gave the mine a multiyear contract in August 1942 for 16.5 million pounds of copper to be refined from the ore concentrate. Mining of ore, which contained between 1 and 3 percent copper, began in spring 1943. Vermont Copper Company president George Ellis stepped down and was replaced by Frederick W. Snow, an experienced mining engineer educated at the Utah School of Mines. In October 1943 the mill began making a 28 percent concentrate, recovering more than 90 percent of the copper in the ore. The concentrate was trucked to the Boston & Maine Railroad at Pompanoosuc Depot on the Connecticut River on a 12.5-mile road, now Vermont Route 132, paved with funds from the U.S. Public Roads Administration in the interest of national defense. The ore was transferred to railroad cars for shipment to a Phelps Dodge Copper Company smelter at Laurel Hill, Long Island, for refining.

Vermont governor William H. Wills, Vermont Copper Company president George A. Ellis, and former governor Stanley C. Wilson inspect the Elizabeth Mine in 1943. Source: Strafford Historical Society.

Two views of the World War II–era mine plant taken about 1960, shortly after the mine closed. Buildings were made according to wartime emergency temporary construction standards. Photo at right shows the cylindrical ore storage bin, flotation mill, and thickener/dryer building. The mill buildings were constructed using heavy timbers salvaged from a Bethel, Vermont, granite-cutting shed. Source for both photos: Collamer Abbott Collection, University of Vermont Library.

Wartime labor shortages, particularly lack of skilled miners, prevented the mine from reaching full capacity, and 50 workers from Newfoundland were hired to help fill the labor gap. The mine produced about 3.8 million pounds of copper a year in 1944 and 1945.

After the end of World War II in 1945, the price of copper fell, and labor shortages persisted as some workers left to return to farming. New miners were hired from Colorado and Canada. Exploratory drilling revealed more ore below the 600-foot level, and plans called for eventual extension of the winze down to a 975-foot level. In 1946 mining reached the 725-foot level, and copper production reached 6 million pounds. Underground mining had extended so far north of the 1898 adit and so deep below the 300-foot level that hauling ore south back up the long inclined winze, east out the 1,400-foot-long adit, and then north to the surface mill had become inefficient. The Vermont Copper Company sank a new vertical shaft about 1,000 feet northwest of the 1898 adit and drove a new adit to intersect it, providing better access to the ore deposit as underground mining progressed to the north. Output fell to 4.4 million pounds in 1947 and 1948, and although copper was in short supply and prices high, the mine was losing \$15,000 to \$20,000 a month. The company spent \$250,000 on unsuccessful experiments to extract and sell pure iron from the pyrrhotite mill tailings.

The Vermont Copper Company was determined to become profitable in 1949 or face possible shutdown. Early that year the company signed a new four-year contract with the U.S. government for 30 million pounds of copper at 19.25 cents a pound and obtained a \$150,000 government loan. Company president and general manager Frederick Snow died and was replaced by Frank Eichelberger, a mining engineer with a reputation for profitable management and extensive experience with froth flotation. Eichelberger cut costs, mined the richest visible underground ore, and boosted the total volume of ore going through the mill with ore left in surface dumps from earlier mining at the Elizabeth and Ely mines. Despite difficulties milling the oxidized dump ore, a recession that lowered the price of copper to 16 cents a pound, and a Phelps Dodge smelter strike, the Vermont Copper Company turned its first profit in June 1949. The Reconstruction Finance Corporation then funded construction of

Headframe tower for the 1948 shaft. Cables from the hoist room ran over grooved sheave wheels, or pulleys, at the top of the tower and were attached to the ore skip and man cage that traveled up and down the shaft to the 975-foot level. Source: Strafford Historical Society.

a larger crusher plant, and Eichelberger expanded the mill capacity to process 750 tons of ore per day. Copper output for 1949 rose to 6 million pounds.

The price of copper rose to 24 cents a pound by the end of 1950, when new exploration proved reserves of rich copper ore extending north underground all the way to the West Branch of the Ompompanoosuc River. The Vermont Copper Company hired a contractor to excavate the ore from the South Open Cut, a surface deposit several hundred feet south of the North Open Cut, to provide additional fresh ore for the mill. This ore ran out in 1953, but it did provide a boost in the quantity of fresh ore for the mill, contributing to record production of 7 million pounds of copper in 1950.

Demand and price for copper rose with the onset of the Korean War in 1951. The idea of extracting sulfur from the South Strafford ore first considered by the early nineteenth-century Vermont Mineral Factory Com-

An electric mine locomotive exits the 1898 adit with a load of copper ore for the mill, sometime during the 1950s. Mine locomotives took electricity off an overhead trolley wire. Source: Strafford Historical Society.

Froth flotation tanks in the flotation mill, 1950s. The dark foam dripping off the top of the tanks is finely ground copper ore that has been attracted to chemical bubbles. Source: Strafford Historical Society.

View looking north along the mine surface railroad, in the 1950s. Spur track at left leads into the machine shop, where mine locomotives, ore cars, and heavy equipment were serviced and repaired. The round concrete ore storage bin for the processing mill is at right. Source: Strafford Historical Society.

Underground Mining

The miners performed a series of tasks to mine the copper ore and bring it to the surface for processing, as shown in these images from the Elizabeth Mine from the 1950s. Source: Strafford Historical Society.

1. Drilling: Miners first drilled a pattern of holes in the rock with compressed-air drills to place timed explosive charges to break the ore into pieces.

2. Mucking: They next pulled the "muck" or broken ore from the working face to a loading station with a "slusher," a motorized scraper pulled by cables.

3. Loading: Next the ore was scooped up with a small mucking machine—an electric bucket loader—and dumped into a string of mine cars.

4. Tramming: Miners then pulled the loaded ore cars to the nearest shaft with an electric or diesel-powered mine locomotive.

5. Hoisting: The ore and also the miners, as shown here, were transported inside the mine in vertical or inclined shafts.

6. Timbering: Once the ore was removed, miners had to secure the rock walls with large timber posts to prevent dangerous rock falls.

pany was finally realized. The Vermont Copper Company began recovering the pyrrhotite from the flotation mill tailings for shipment to the Brown Paper Company of Berlin, New Hampshire, for extraction of sulfur for sulfite-process wood pulp treatment for papermaking. This process resulted in additional profit from 25,000 tons of pyrrhotite concentrates a year that had previously been discarded in the tailings pile, which had begun to fill the Copperas Brook valley below the mill.

A miner poses with an electric mine locomotive, which is protected from falling rocks by the sheet metal cover, 1950s. Source: Strafford Historical Society.

Mine plant looking northwest in the 1950s. The foreground tailings pile was the second one created, south of the first, after separation of the pyrrhotite in the ore for the Brown Paper Company began in 1951. Source: Strafford Historical Society.

Cable shovel excavating copper ore from the South Open Cut in the early 1950s. Source: Strafford Historical Society.

Mine Safety

Hard-rock mining was and still is dangerous work. As early as the 1830s, the Vermont Copperas Company recorded the death of a James Richards from a premature blast, and in 1863, company agent William Reynolds wrote, "Yesterday was a rather unfortunate day for us, an ox was killed by a stone from a blast and one of the men had an eye put out." Accidental injury and death were not infrequent during early mining periods at South Strafford.

The U.S. Congress passed the first federal mine safety laws in 1891, setting ventilation requirements for coal mines and prohibiting workers under the age of 12. Congress established the U.S. Bureau of Mines in 1910, but its focus was primarily coal mining safety research, and it had no inspection authority until 1941. Increasingly stringent federal legislation, including inspections and fines, was passed in 1947 and 1952, but still just for coal mines. The first federal safety laws for non-coal mines, the Federal Metal and Nonmetallic Mine Safety Act of 1966, was enacted eight years after the Elizabeth Mine closed. The 1977 Federal Mine Safety and Health Act was even stronger and reduced mine fatalities by more than 60 percent.

Although safe work practices and equipment at hard-rock metal mines like the Elizabeth Mine were not federally regulated in the 1940s and 1950s, safety was very much part of workplace culture. Elizabeth Mine superintendant Richard Little said in 1957, "A man's attitude undergoes a big change underground. He knows the man working with him is dependent on him for his safety. A false move, a little bit of carelessness. . . . Mines are no place to fool around. This is serious business and the men realize it." Safety was also good for business, as accidents raised corporate insurance rates. The Elizabeth Mine had its own preventive safety program and facilities, including a first aid station with a company nurse. Despite the safety program, accidents happened. One miner was killed in 1948, and two died in separate blasting accidents in 1945 and 1956. The most dramatic, fortunately nonfatal, accident was in 1952, when the shaft hoist operator fainted while lowering eight men into the mine. The hoist reversed direction, slamming the cage the men were in up into the shaft tower and hurling them 40 feet to the ground.

Elizabeth Mine foreman Charlie Judd's 1950s hard hat. Note the round brass miner's identification number tag attached to the hat. Source: Strafford Historical Society.

An Elizabeth Mine change house attendant at the miners' helmet lamp battery-charging station. Each miner's numbered identification tag was hung on a peg on the triangular panels to show who was working underground at any given time. Source: Strafford Historical Society.

Vermont Copper Company miners pose in front of the 1898 Tyson adit, still in use in this World War II–era photograph. Prominently posted safety signs were part of the Elizabeth Mine's corporate safety program. Source: Strafford Historical Society.

The years immediately after the Korean War were a time of productivity, profitability, and change for the Elizabeth Mine. The Vermont Copper Company signed a government contract for 12 million pounds of copper for just over 31 cents a pound in 1954. That June the Vermont Copper Company sold the Elizabeth Mine to Appalachian Sulphides Inc., a subsidiary of Nippissing Mines of Canada, for $365,000. The new company acquired mining rights to over 8,000 acres in the Vermont Copper Belt and prospected for copper elsewhere in the Appalachian Mountains. Improvements in equipment and a steadier labor force boosted Elizabeth Mine productivity. Mill capacity rose to an average of 800 tons per day in 1952. Although small compared to some western U.S. mines, the Elizabeth Mine was the nineteenth-largest copper producer in the country in 1953. Annual production rose above 8.5 million pounds in 1954 and 1955, and recovery of trace amounts of silver and gold in the ore at the refinery added to profits. Employment reached a high of 220 workers, and annual payroll was more than $1 million. Copper sales were over $3 million. The most successful year was 1955, when the mine profit was $1,016,705.

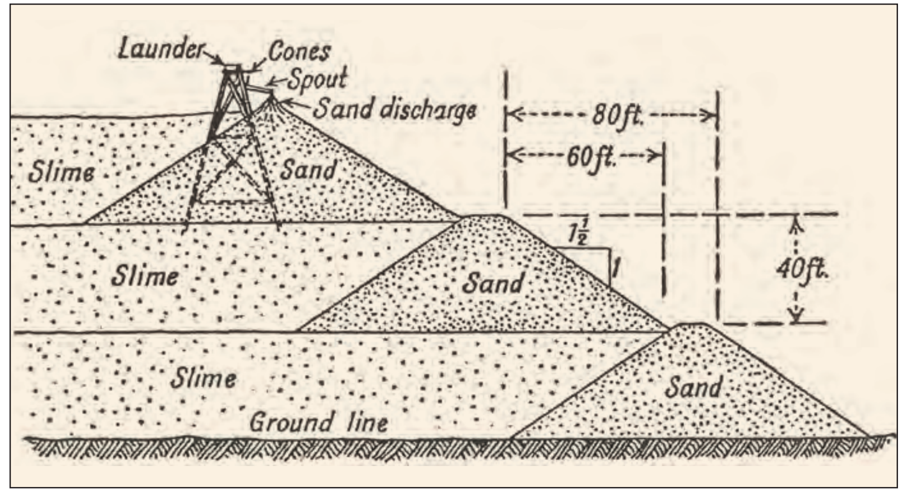
Elizabeth miners enjoy a meal in the underground break room, 1950s. Source: Strafford Historical Society.

Underground mining finally extended 1,600 feet north of the bed of the Ompompanoosuc River, where a small utility shaft connected to the surface. The underground workings extended 7,800 feet horizontally and included about 5 miles of tunnels. Copper prices fell from a 90-year peak of 46 cents a pound in 1956, and the ore deposit began to diminish in size and richness, falling below the 1.5 percent copper grade needed to break even. Elizabeth Mine copper production dropped below 7 million pounds for 1956 and 1957, and the number of employees dropped to 180.

Appalachian Sulphides already knew the end was near for the Elizabeth Mine, and had been using its Vermont profits to reopen the historic Ore Knob copper sulfide mine in Laurel Springs, Ashe County, North Carolina. The last chapter in the long history of mining at South Strafford ended in February 1958, when Appalachian Sulphides shut down the Elizabeth Mine. In March, 30 men were left to salvage equipment and seal off the mine entrances. Appalachian Sulphides moved most of the mining and ore concentrating equipment to Ore Knob, and mined and concentrated copper ore there until 1962. Some management staff and miners followed the company south, but most workers remained in Vermont.

The unwanted ground waste tailings were pumped away from the flotation mill in a liquid slurry through a "launder"—a series of pipes and troughs that led out to the tailings pile. Source: Strafford Historical Society.

A 1948 photograph shows ore mill tailings flowing out of the movable launder at the front edge of the ever-expanding tailings pile, which eventually filled the Copperas Brook valley and became the largest landscape feature associated with the 1943–1958 operations. Source: Strafford Historical Society.



Technical illustration of a tailings pile in cross-section. Coarse tailings were deposited at the front to form a series of dams, and finer material was pumped in behind them. A system of interior drain pipes collected water. Source: Arthur F. Taggart, *Handbook of Mineral Dressing*, 1927.

Some engineers and geologists took jobs with the Vermont Highway Department. Other miners returned to farming or looked for new jobs. The local economy had lost its biggest payroll, and its second-biggest employer.

The Elizabeth Mine produced between 10 and 19 million pounds of copper before its World War II revival in 1943. During the subsequent 15-year campaign the mine produced 91,495,800 pounds of copper, and probably had a total lifetime output of just over 100 million pounds. Elizabeth Mine copper production ultimately outstripped its nineteenth-century counterpart, the Ely Mine at Vershire. In 1950 there were three hundred copper mines in the United States. The top five produced 67 percent of U.S. copper, and the top ten produced 85 percent. Between 1946 and 1956 the Elizabeth Mine was at times among the top twenty-five producers. It was twentieth in five of those years and nineteenth in one. It was the largest copper mine in New England, and the largest in the Appalachians working from a single ore body. When it finally closed, it left behind the largest mining landscape and greatest environmental impacts of all the Orange County copper mines.

The Elizabeth Miners

The Vermont Copper Company recognized the value of positive employee relations and morale. The company provided a modern benefit and sickness insurance plan, and the employees formed a welfare club to collect money for injured workers. The company formed a "Labor-Management Committee" and encouraged employee suggestions for workplace safety and recreation ideas. Sports were part of workplace culture, and miners formed their own baseball team, named their playing diamond the Copper Bowl, and played teams from surrounding towns.

The Vermont Copper Company employees published their own magazine, the *Elizabeth Miner*. Most content was lighthearted, including cartoons, jokes, humorous anecdotes from on and off the mine property, miners' family news, and announcements and reports of company events such as picnics and baseball games. The magazine included information about operational or management changes affecting workers and was also a venue for frequent safety reminders. Occasional technical articles provided insights into the different jobs at the mine, which were sometimes mysterious to workers in other departments.

During World War II the *Elizabeth Miner* was also a patriotic booster, providing news about former miners serving overseas. The mine even had its own wartime theme song, sung to the tune of "Roll Out the Barrel":

Roll out the copper,
  We've got the Japs on the run.
Roll out the copper,
  We're giving the Nazis the gun.
Boom! Boom! for victory,
  We'll soon ring bells of good cheer.
So keep your courage way up,
  For our gang's all here!

Shortage of skilled and unskilled labor during and after the war was chronic, and the Vermont Copper Company tried to appeal to workers to take mining jobs in South Strafford. The mine employed men from as many as 16 different communities within 30 miles of the mine. Management recognized the need to accommodate local labor and embraced the idea of the "farmer-miner," offering flexible seasonal and daily work schedules for workers who needed to take a season off for planting or harvesting, or even just a day off to go hunting. Wages in 1949 were 65 cents an hour, with some underground work paying as much as 90 cents, reportedly the highest hourly wages in Vermont at the time. Despite a goal to employ only Vermont workers, the mine had to hire outside labor from as far as western U.S. mining districts and Canada to operate at full capacity.

Center: *Elizabeth Miner* cover. Source: Strafford Historical Society. Left: Mine employee photo identification tags. Source: U.S. Environmental Protection Agency.

Elizabeth miners pause for a friendly group portrait underground in the 1950s. Source: Strafford Historical Society.

Aerial view of partially overgrown copper ore mill waste tailings pile in Copperas Brook valley looking southwest, 1990s. Copper ore was processed and separated from the tailings in the mill buildings at center right, 1943–1958. About 2.8 million cubic yards of tailings were discarded in the 45-acre pile, which is a quarter of a mile wide on its 150-foot-high north face. The North Open Cut and copperas works area are visible at upper right. Source: Strafford Historical Society.

From Closure to Cleanup: The Environmental Legacy of Mining, 1958–2000

After Appalachian Sulphides, Inc. closed the Elizabeth Mine in 1958, new private owners purchased the mine land parcels. Undisturbed wooded areas were used for logging and a construction company set up shop in the World War II buildings complex. Former mine buildings along Mine Road became private homes. The mine became a popular site for regional academic environmental and geological studies.

Almost 150 years of mining for copperas and copper left a large and unusual historic cultural and industrial landscape. Dramatic features like the colorful copperas roast beds and heap leach piles, and the massive 1940s–1950s mill tailings piles, were distinctive expressions of technology applied to processing minerals over the life of the mine. This compelling manufactured landscape was visible evidence of the sheer effort involved in mining and the monumental, rapid changes it makes to the land.

The mine landscape was also tangible evidence of "boom and bust" attitudes toward land and natural resources, which were historically exploited until they were spent and then abandoned. In the nineteenth century, the vast American interior was viewed as a source of inexhaustible wealth. The need for raw materials critical for economic and technological advancement outweighed concern for environmental impacts, and the hand of man on the landscape was considered a sign of prosperity. Metal mining was tied to wartime needs, and new markets and technology. The growth of the electrical industry in the late nineteenth century boosted demand for copper, and during World War II and the Korean War, strategic mineral requirements made many smaller copper mines like the Elizabeth Mine economically viable. Introduction of twentieth-century technology such as froth flotation, which allowed mining of much larger, low-grade ore deposits, left much larger accumulations of mine waste.

Acid mine drainage flowing from the 1898 Tyson adit, 2003. Source: U.S. Environmental Protection Agency.

Increasing public concern over industrial degradation led to the environmental movement of the late 1960s and early 1970s. In 1970 the U.S. Environmental Protection Agency was established and the first "Earth Day" celebration was held. The EPA created the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, more commonly known as "Superfund," which compels responsible parties to cover site cleanup costs. Through 2008, the EPA expended an estimated $2.2 billion responding to mining-related Superfund sites. Mining is still essential to our way of life today, and current U.S. mining regulations require planning for environmental protection during mining and post-mining site reclamation as part of new mine development.

Metallic sulfide ore deposits like the Elizabeth Mine are unusual natural concentrations of minerals. While undisturbed sulfide ore deposits can generate acid and release metals, mining greatly aggravates the potential for environmental degradation by concentrating and exposing ore and waste to water and oxygen. Sulfide, water, and oxygen are the three key ingredients of acid mine drainage. At the Elizabeth Mine, the historic industrial landscape was also the source of the hazards being released from the mine site. The copperas heap leach piles were releasing sulfuric acid and metals including cadmium, cobalt, copper, and zinc. The World War II tailings pile was releasing large quantities of dissolved iron and acidity. The soil at the copperas factory sites contained high concentrations of lead. These uncontrolled releases of sulfuric acid and metals were impacting the aquatic ecology of Copperas Brook and the West Branch of the Ompompanoosuc River, a tributary of the Connecticut River.

Aerial view looking southwest in 2003 showing ore mill tailings at center, World War II–era buildings at center right, Mine Road above and copperas works area with North Open Cut near top. Hillside topography funneled surface and groundwater through the site, gathering acid and metals and carrying them north into the Ompompanoosuc River. Source: U.S. Environmental Protection Agency.

Copperas Hill looking west in 2009 showing North Open Cut at center. The 1880s–1890s Tyson mining area is at center right, reddish copperas manufacturing roast beds / heap leach piles with Copperas Road are at center, and upper copperas factory site is at lower right. Source: U.S. Environmental Protection Agency.

Eroded copperas manufacturing roast beds / heap leach piles on Copperas Hill. The leachate from this area produced copper concentrations in Copperas Brook over 5,000 times greater than the Vermont water quality standard of 11.8 parts per billion.

North end of 1,000-foot-long North Open Cut looking north, showing open stopes (chambers) where mining extended north underground, 2010. Source: U.S. Environmental Protection Agency.

View from 2003 looking southwest across larger tailings pile to smaller one deposited when pyrrhotite extraction began in 1951. Water flowing through the tailings discharged dilute sulfuric acid and up to 800 pounds of dissolved iron a day into Copperas Brook. Source: U.S. Environmental Protection Agency.

South Open Cut looking northeast in 2007, with portion of copperas works area at upper left. The 1,600-foot-long cut was surface mined for copper ore from 1950 to 1953. Runoff from the cut and nearby South Mine contributed copper to the watershed of Lord Brook, also a tributary of the Ompompanoosuc, and ultimately, the Connecticut River. Source: U.S. Environmental Protection Agency.

Lower copperas factory foundation on Mine Road, 2009. Copperas manufacturing from 1809 to 1882 involved lead-lined vats and plumbing, which left small but highly lead-contaminated areas in and immediately around the two factory foundations. Source: U.S. Environmental Protection Agency.

Elizabeth Mine looking southwest, 2012. The 1943–1958 ore mill tailings, named tailings piles (TP) 1 and 2 by the EPA, became the repository platform for over 356 thousand cubic yards of consolidated mine waste, excavated from Mine Road, the South Mine, the South Open Cut, the copperas factories, the TP-1 and TP-2 perimeter, and the copperas works roast beds / heap leach piles (TP-3), visible in the background below the North Open Cut. Source: U.S. Environmental Protection Agency.

Reclaiming The Land: The Elizabeth Mine Cleanup, 2000–2013

The sulfuric acid and metals leaching from the Elizabeth Mine waste piles were severely affecting the aquatic life in nearby streams. In 2001 the Environmental Protection Agency designated the Elizabeth Mine a Superfund site, which made federal resources available for study and cleanup.

The EPA's cleanup approach was to consolidate all mine waste in one place and isolate it from water and oxygen by capping it and diverting water around it. The EPA chose the existing, large 1943–1958 flotation mill tailings, renamed Tailings Piles (TP) 1 and 2, as the location for all mine site waste. Between 2003 and 2005, the EPA stabilized the eroded banks of TP-1 with a soil buttress. Between 2006 and 2010, the EPA constructed diversion trenches to reroute Copperas Brook and groundwater around TP-1 and TP-2. All waste rock and leach piles from the steep copperas works hillside, renamed TP-3, were removed by multiple bulldozers and backhoes, and transported to TP-1 by a small army of giant dump trucks. In 2008, an interim treatment plant was installed to remove the iron in the water leaching from TP-1. Between 2009 and 2010, the EPA removed the majority of the lead-contaminated soil at the copperas factories and placed it on TP-1. The lead-contaminated soil left within the footprint of the copperas factories was covered with two feet of rounded stone to prevent human contact and to highlight the surviving foundations. The World War II ore processing buildings were demolished and surrounding waste rock removed, and the tiered concrete foundations and machinery pads were left in place to interpret the gravity-fed ore milling process. Between 2011 and 2013, mine waste was removed from other areas, including the South Mine and South Open Cut, and relocated to TP-1. The EPA graded the consolidated material and installed a cover system including a plastic membrane to block water from infiltrating into the waste, and two feet of soil to protect the membrane and grow grass. The cover system provides a large, environmentally safe area designed and constructed to be compatible with possible future uses. Long-term monitoring and maintenance of the mine site will be performed to make sure the cleanup remains effective.

The cleanup actions implemented through 2013 have been successful. Leachate flow from TP-1 and TP-2 has dropped from 60 gallons per minute to 22 gallons, and continued decreases in flow are expected. The interim treatment plant removes 99 percent of the iron in the leachate discharge from TP-1. The copper concentration in Copperas Brook has dropped more than 95 percent. Before cleanup started, all of Copperas Brook and four miles of the West Branch of the Ompompanoosuc River were significantly impacted by the acid mine drainage from Elizabeth Mine. Biological monitoring from 2010 to 2013 shows dramatic recovery of the aquatic ecology for the river. Final cleanup steps will address the long-term solution for the leachate flowing from TP-1 and metal-contaminated water flowing from the South Mine and South Open Cut into Lord Brook.

The Elizabeth Mine's former industrial-period landscape features were massive, but ultimately temporary, expressions of site history. The mine site landscape continues to evolve, and although the new, reclaimed landscape is very different, it is in some ways just as dramatic as the one it replaced. ▲

On the steep slope (TP-3) below the North Open Cut, approximately 243,000 cubic yards of copperas roast beds / heap leach piles and waste rock associated with later copper mining were excavated down to bedrock and hauled to the repository for burial. Source: U.S. Environmental Protection Agency.

Once TP-3 was scraped clean, Copperas Road was reconstructed across it, and rock-lined drainage culverts were installed. Historic diagonal bedrock trench made to direct weak liquid copperas to the factories is clearly visible below the road. Waste removal resulted in over 95 percent reduction in copper discharge from the hillside. Source: U.S. Environmental Protection Agency.

To prepare TP-1 for the waste repository, its steep, eroded sides were regraded for stability. Excavation revealed the unoxidized black pyrrhotite (iron sulfide) under the weathered outer orange layer of tailings. Source: U.S. Environmental Protection Agency.

Once mine waste was consolidated on the tailings pile area, it was graded to shed water, and covered with an impermeable plastic barrier, which is being unrolled and sealed in this view across the top of the capped waste. The plastic barrier was then buried under two feet of soil. Source: U.S. Environmental Protection Agency.

The top and sides of the sealed cap were covered with over two feet of soil, which was treated with lime, fertilized, and planted with grass. Rock-lined trenches divert surface runoff off and around the cap. Water filtration has been reduced so that the tailings now discharge less than 100 pounds of dissolved iron per day — about 88 percent less than the peak discharge of 800 pounds per day. Source: U.S. Environmental Protection Agency.

The remaining World War II–era mine buildings were cleared of asbestos, and historical artifacts were salvaged. Except for the assay laboratory and miners' change house, which were stable and left standing, buildings were demolished, and the debris was capped. Mill building foundations were left in place. Source: U.S. Environmental Protection Agency

A water-treatment plant was installed to remove the dissolved iron in the leachate from the repository during and after construction. The leachate is mixed with lime, neutralizing the acid and removing 99 percent of the iron as inert orange iron oxide. A drainage trench is visible along the right side of the cap. Source: U.S. Environmental Protection Agency.

Mine waste rock fill and accumulated sediment from copperas waste piles in the area flanking the sharp bend in Mine Road near the copperas factories were relocated to the repository. Mine Road was removed, reconstructed, and temporary basins were installed to capture sediment from TP-3 while it was being scraped clean. The lower copperas factory foundation is visible in the background. Source: U.S. Environmental Protection Agency.

Archaeologists from PAL Inc. conducted excavations in 2009 and 2010 to reveal workings of the 1809–1882 copperas factories. A small backhoe dug exploratory trenches in overburden, and factory features were excavated by hand. Excavations revealed intact remains of masonry vessels associated with all three stages of copperas making. The brick structure in the foreground is part of a copperas cooling and settling vat at the lower factory. Iron posts and rods originally held the vat sides together. Lead sheet at lower right was used for vat lining. Source: U.S. Environmental Protection Agency.

The Elizabeth Mine's importance as a historic property was clear to the Environmental Protection Agency from the agency's earliest interactions with the towns of Strafford and Thetford and the State of Vermont. The Vermont Division for Historic Preservation (VTDHP) and the local community were emphatic that the historical significance of the Elizabeth Mine be considered in planning and implementing the cleanup. The EPA organized the Elizabeth Mine Community Advisory Group, which included the Strafford Historical Society, the Strafford and Thetford select boards, and seven other local interest groups, to work closely with the local community.

Section 106 of the National Historic Preservation Act requires federal agencies to take into account the effect of their undertakings on historic properties. To meet this requirement, the EPA assembled a team of historic resource experts to evaluate the Elizabeth Mine's historic significance. Based on their findings, and with the concurrence of the State Historic Preservation Officer, the EPA determined that the Elizabeth Mine is eligible for listing in the National Register of Historic Places as a historic property.

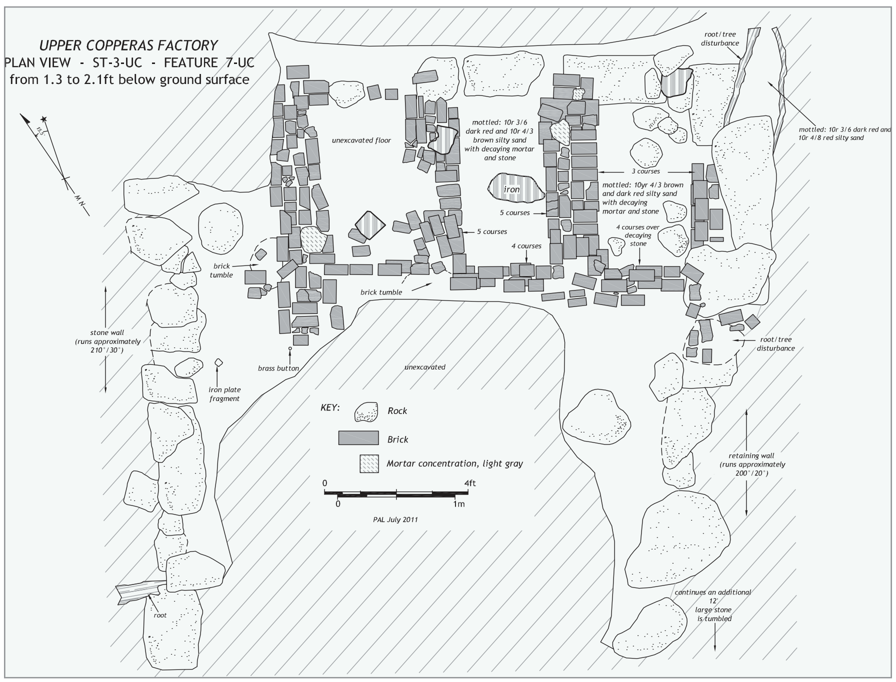
The EPA, the VTDHP, and other consulting parties entered into a memorandum of agreement stipulating how the cleanup's adverse impacts to this historic property were to be mitigated. The major mitigation activities included detailed written and photographic documentation of the historic buildings and landscape; archaeological investigations of the copperas factories; monitoring during cleanup activities; support for a video documentary about the Elizabeth Mine; planning in support of future interpretation activities; and this popular report.

Archaeologists survey surviving lower copperas factory foundation.
Source: U.S. Environmental Protection Agency.

Several aspects of mine history and specific parts of the mine site were identified as worthy of additional investigation and documentation: the 1809–1882 copperas factories and the World War II–era buildings and associated mining landscape features. The detailed description and drawings of the World War II–era site that were created are shown on pages 54–57.

The Elizabeth Mine is a well-documented historic property as a result of these efforts. While the mining landscape has been dramatically changed through the cleanup efforts, the site retains many of its characteristic features, which still serve as a reminder of the colorful story of the Elizabeth Mine.

Once archaeologists excavated features, such as this floor area at the lower copperas factory, shown at left, they documented them in scaled field drawings using a grid and tape measure. Source: U.S. Environmental Protection Agency.



Plan view drawing of upper factory copperas boiler foundation, which corresponds closely to an 1821 description: "The bottom is supported by a number of parallel brick walls, placed at a small distance from each other. The avenues or arches between these walls communicate at one end with the arch in which the fire is placed, and at the other with the common flue." Source: U.S. Environmental Protection Agency.

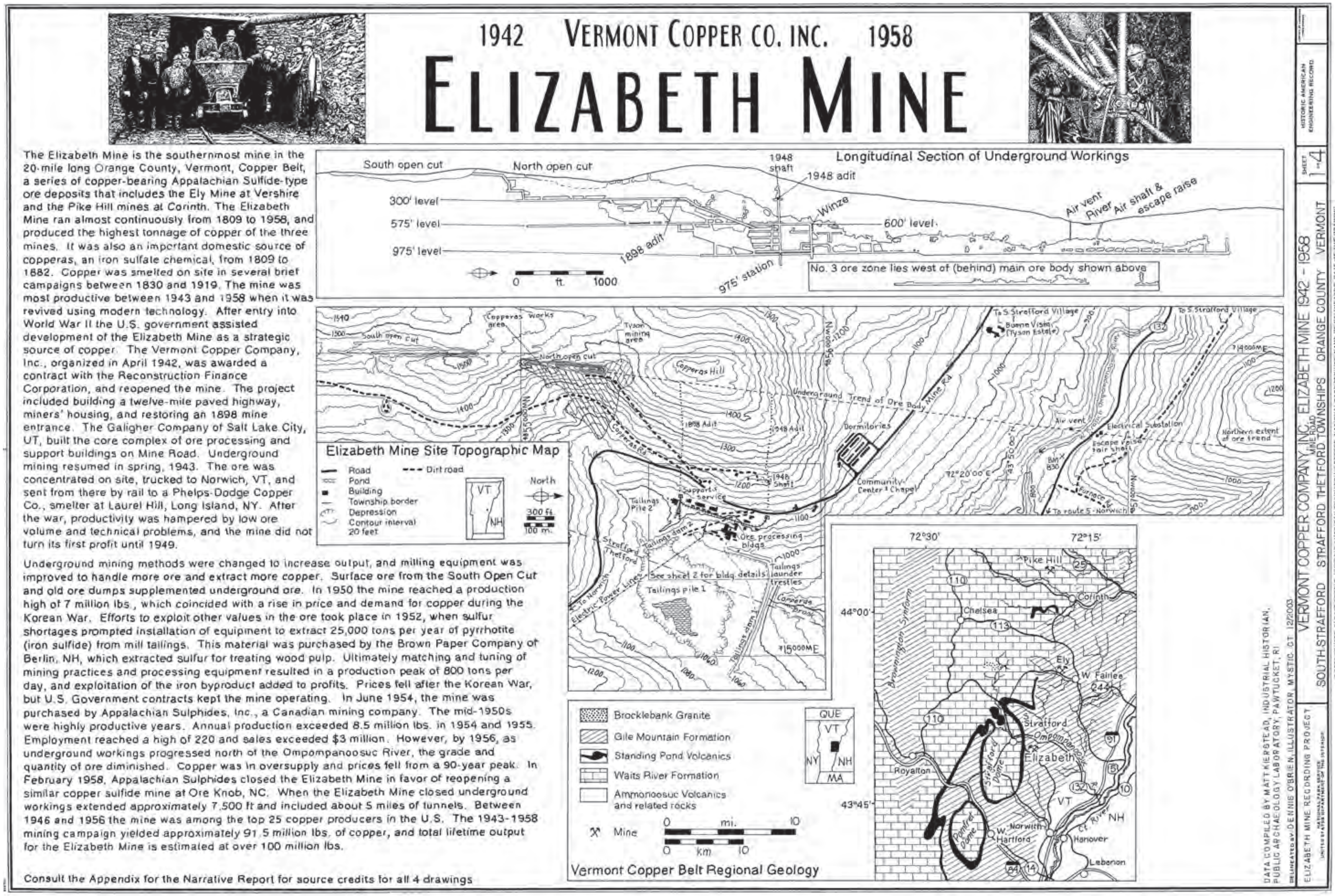
Excavations within the terraced upper copperas factory site uncovered masonry remains of the three major successive steps in copperas production: boiling, cooling/settling, and crystallizing. The brick floor of this crystallizing vat was particularly well preserved. Source: U.S. Environmental Protection Agency.

Artifacts recovered from the copperas factories include glass and nails from the buildings, tools such as ax heads for making wood shipping barrels and casks, and furnace parts. Artifacts also included lead sheet and pipe and this wrought-iron lead-melting ladle for repairing linings and plumbing for copperas vessels. Source: U.S. Environmental Protection Agency.

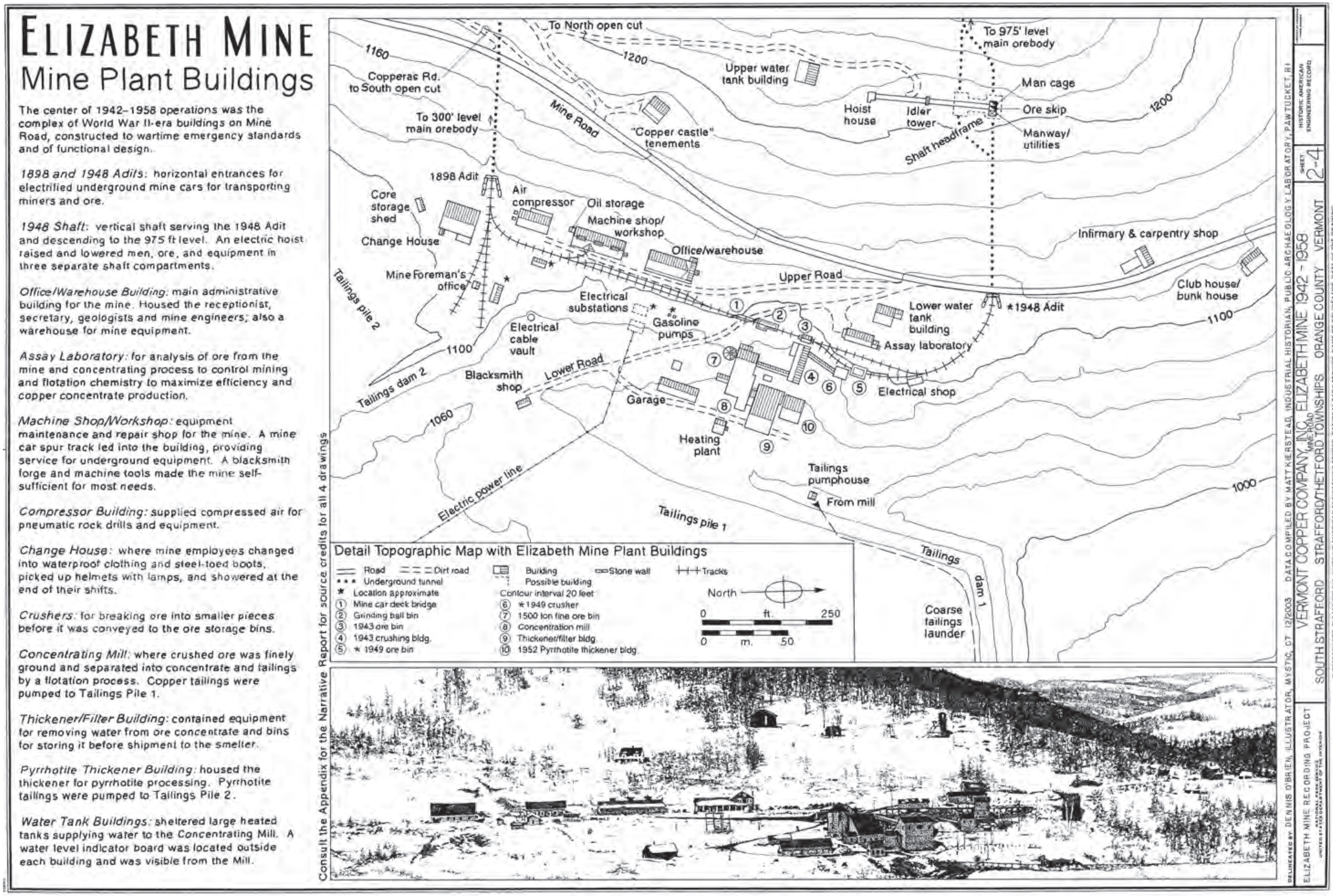
The World War II–era ore mill concrete foundations were cleared and retained. From left to right are foundations for the primary ore crusher, the thickener/dryer building, the timber ore concentrate bin supports, the flotation mill, and the round crushed-ore storage bin. The completed mine waste repository lies behind the mill foundations. Source: U.S. Environmental Protection Agency.

Site documentation also focused on the World War II–era buildings and landscape features and includes a set of 66 black-and-white photographs taken with a large-format architectural view camera, such as this view of the copper ore flotation mill and thickener/dryer building. Source: Rob Brewster, Warren Jagger Photography.

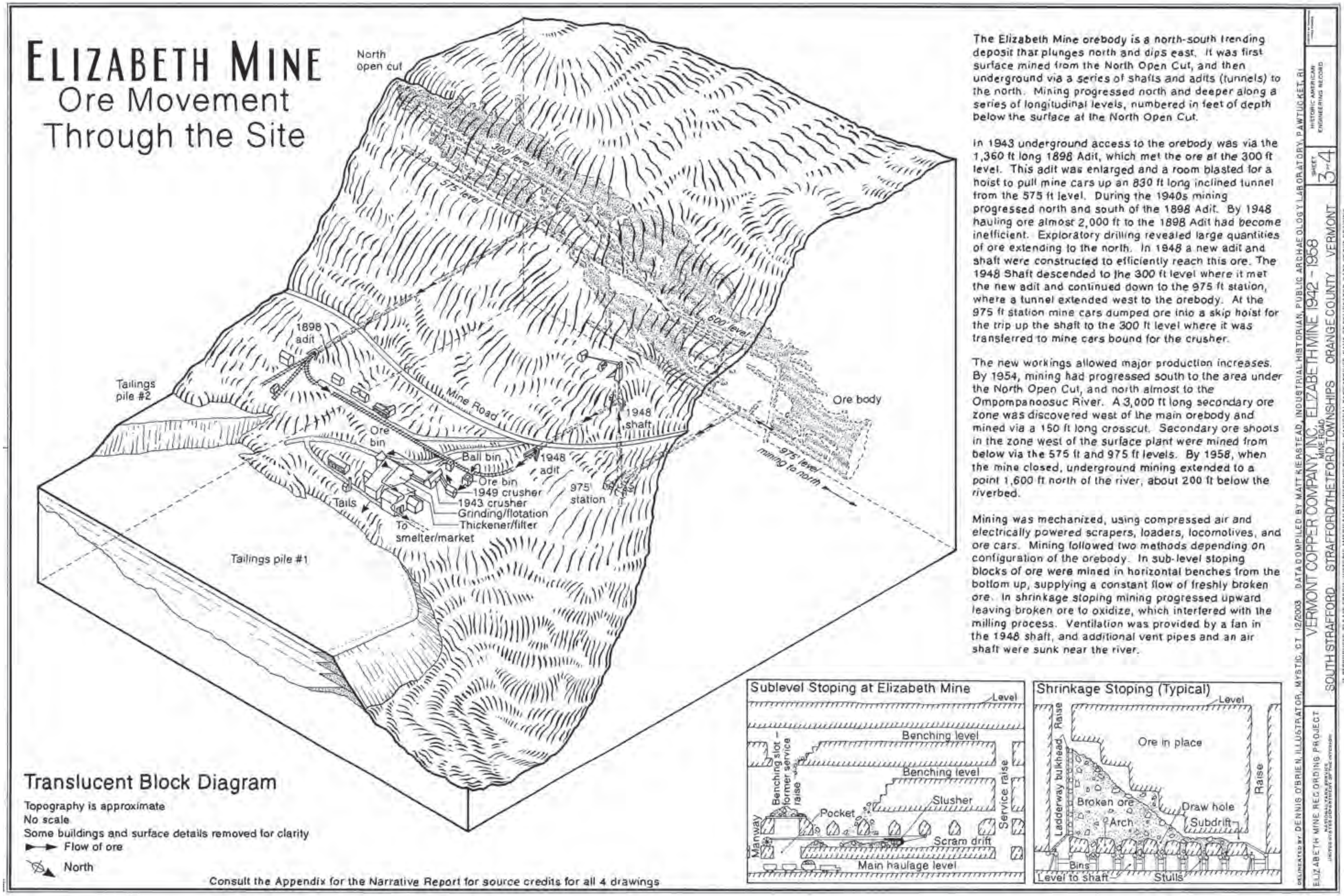
Site reconstruction included replacement of Mine Road at the copperas factories site. The topography of the area around both factory foundations was carefully surveyed, lead-contaminated soil was relocated to the repository, and the extent of the formerly contaminated areas were marked with crushed stone, matching the contours of the original ground. Source: U.S. Environmental Protection Agency.



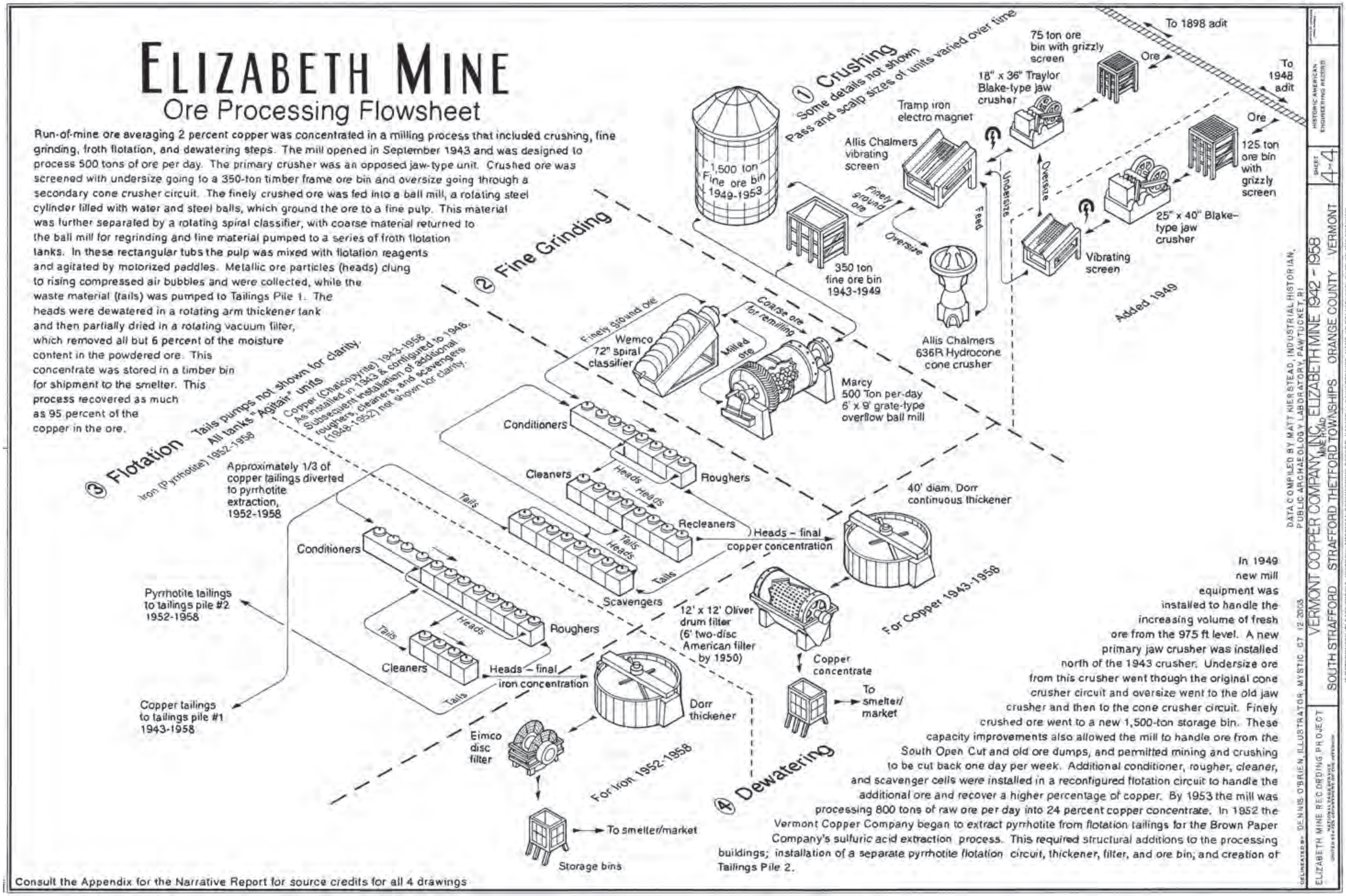
Documentation of World War II–era resources included four drawings showing aspects of site history best expressed graphically. Drawing 1 shows the mine site in plan, the underground workings in corresponding profile, and the geological context. Source: Dennis O'Brien Maps & Wayfinding.



Documentation drawing 2 shows the mine plant surface buildings corresponding to a historical view, as well as underground mine entrances and mine railroad connections. Source: Dennis O'Brien Maps & Wayfinding.



Documentation drawing 3 shows surface plant connections to the underground workings and how mining was conducted within the ore body. Source: Dennis O'Brien Maps & Wayfinding.



Documentation drawing 4 flow diagram shows successive steps of copper ore processing and waste tailings disposal, including expansions for added capacity and pyrrhotite extraction. Source: Dennis O'Brien Maps & Wayfinding.

Environmental scientists collect water samples from monitoring wells to understand the chemistry of Elizabeth Mine ore mill Tailings Pile 1. Source: U.S. Environmental Protection Agency.

Conclusion: Linking Past, Present, and Future

The Elizabeth Mine in South Strafford, Vermont, was a remarkable part of New England industrial history over a century and a half of operation between 1809 and 1958. The nineteenth century was an era of creativity and innovation at the mine, which was then the largest U.S. producer of copperas and the site of several firsts in copper smelting. In the twentieth century, mass-production technology made it the most productive copper mine in New England, and, briefly, one of the more productive in the United States. The mine contributed about 100 million pounds of copper to American industry. Mining also left a dramatic landscape that contaminated area brooks and rivers for over forty years. At the start of the millennium, the U.S. Environmental Protection Agency began a Superfund cleanup project that resulted in a dramatic reduction of acid and metals released to the environment and the return of aquatic life. Input from the local community regarding the historic importance of the site and desire for future use and public interpretation greatly influenced the design and implementation of the cleanup.

The project was a successful example of integrating history and planning. Historical research revealed that the copperas-making area at Tailings Pile 3 had functioned essentially as a man-made acid drainage and metals concentrator. This was the worst contamination "hot spot," but was also determined to be the most historically significant part of the mine site. Cleanup required removal of all contaminated soil, which was monitored to record buried industrial archaeological features. High soil lead levels at TP-3 were initially inexplicable; however, research into the copperas-making process revealed that remains of lead-lined vessels and plumbing were the source of contamination. The historically significant factories were recorded through archaeological data recovery. Recognition of the historical value of the copperas factories and World War II ore processing mill resulted in creative design that revealed and preserved their foundations for interpretation. Understanding the Elizabeth Mine's history and significance helped shape the cleanup and insured proper documentation and preservation of its most important features.

The story of the Elizabeth Mine followed a historical arc common to industrial sites, especially mines. The natural resource was exploited to support industrial activities and for the benefit of owners and operators in an era when economic gain overshadowed environmental concern. Changes in environmental attitudes have brought about new laws requiring the restoration of landscapes damaged by mining. As the Elizabeth Mine cleanup is being completed, the next chapter in its history is still being written. The EPA is working with the local community, the Vermont Division for Historic Preservation, and the Vermont Department of Environmental Conservation to develop interpretive information about the site so that the story of the Elizabeth Mine can be told to future generations. The Elizabeth Mine site will remain a place where people can learn about our industrial past, its impact on the present, and share our hopes for the future. ▲

Elizabeth Mine historical site marker erected on Mine Road by the Vermont Division for Historic Preservation for the town of Strafford. Source: U.S. Environmental Protection Agency.

Sources Consulted

This source selection reflects the more important archival materials consulted for *From Copperas to Cleanup*, which draws on several U.S. Environmental Protection Agency Elizabeth Mine historic resource technical reports, which in turn draw on a larger body of historical materials too great to list here in their entirety. Major information sources included collections of the Vermont State Library; the University of Vermont Special Collections, Bailey/Howe Library; the Vermont Historical Society Library; the Strafford (VT) Historical Society; Town of Strafford Records; and Dartmouth College Library. EPA Elizabeth Mine historic resource reports are available for study at the Vermont Division for Historic Preservation in Montpelier. For more information about the site history and cleanup, including a link to this document, visit www.epa.gov/region1/superfund/sites/elizmine, http://accd.vermont.gov/strong_communities/preservation/education/archaeology/publications, or www.straffordvt.org/straffordhistory/straffordhistoricalsociety.

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From Copperas to Cleanup — The History of Vermont's Elizabeth Copper Mine

The Elizabeth Mine in South Strafford, Vermont, operated from 1809 to 1958. It was the largest copper mine in New England and hosted technological developments in the American chemical and copper industries, including an important early U.S. "copperas" (iron sulfate) factory. The mine produced 50,000 tons of copper for the American Industrial Revolution, World War II, and the Korean War. Runoff from the dramatic, abandoned mine landscape contaminated the Connecticut River watershed. The U.S. Environmental Protection Agency designated the mine one of the largest Superfund sites in New England in 2001, and cleanup was completed in 2013. *From Copperas to Cleanup* presents, in words and pictures, the story of 150 years of industrial activity at the Elizabeth Mine and how the EPA and its project partners documented and reclaimed its legacy on the landscape.

This popular report was prepared by Milestone Heritage Consulting, subcontractor to Nobis Engineering Inc., contractor for the U.S. Army Corps of Engineers, New England District, to support the EPA at the Elizabeth Mine Superfund site. It was produced in partial fulfillment of a memorandum of agreement among the EPA, the Vermont Division for Historic Preservation, and the Vermont Department of Environmental Conservation.

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