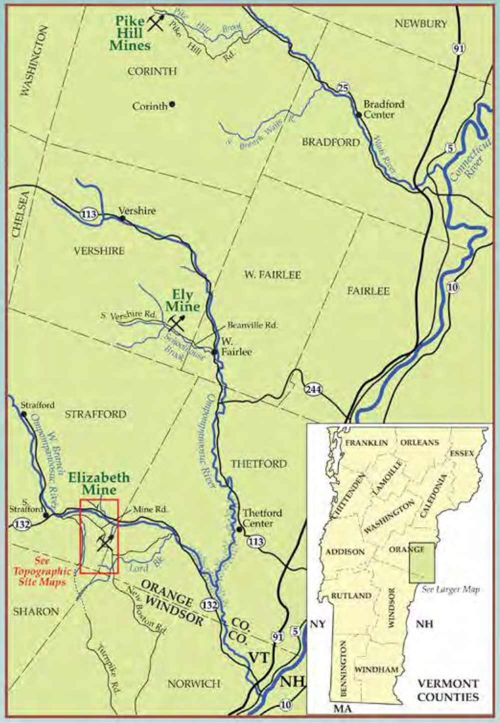
ELIZABETH MINE

You are standing at the center of the Elizabeth Copper Mine site, a scene of widespread industrial activity from 1809 to 1958. The mine was the largest producer of the chemical "copperas" in the United States in the mid-nineteenth century. Modernized for World War II production, it became one of the top 20 American copper ore producers of the 1950s. A century and a half of mining left behind a dramatic landscape of mining waste that contaminated part of the Connecticut River watershed. The U.S. Environmental Protection Agency declared the Elizabeth Mine a "Superfund" site in 2001, and the EPA's cleanup actions have dramatically improved the ecological health of the impacted streams and rivers.

The Elizabeth Mine was a source of metallic, sulfur-bearing minerals. The iron-, copper-, and sulfur-bearing "sulfide" ore minerals mined here were deposited on the ancient seafloor around 400 million years ago and later included in the formation of Vermont's Green Mountains. Sulfide ores and mining waste exposed to air and water can create acid water and metals contamination.

Copper is an important metal with a long history of mining in the U.S.
Copper has been used by humans for thousands of years. Its malleability, strength, and corrosion resistance make it ideal for weapons, containers, coins, statues, musical instruments, and plumbing. Copper is also highly conductive, and by 1900 it was in great demand for electrical and communications uses. Most of the copper used in America during the colonial period was imported. The U.S. copper industry emerged in the 1840s, and Michigan and Vermont became important Civil War–era contributors. Later in the nineteenth century the industry expanded in the Rocky Mountains and the American Southwest, where copper is now mined in huge open pits.

Vermont once hosted New England's most productive copper mines.
Orange County's historic "Copper Belt" includes the Elizabeth Mine, the Ely Mine in Vershire, and the Pike Hill mines in Corinth. These mines operated on and off, based on demand for copper for the American Industrial Revolution, the Civil War, two World Wars, and the Korean War. Together they produced almost 150 million pounds of copper, almost 100 million pounds of which came from the Elizabeth Mine. These mines were "boom and bust" industries where natural resources were exploited and the resulting landscapes abandoned. After the Elizabeth Mine closed in 1958, waste contaminated the water in Copperas Brook, Lord Brook, and the West Branch of the Ompompanoosuc River, tributaries of the Connecticut River, for over forty years.



Sample of chalcopyrite (copper sulfide ore) mined underground at the Elizabeth Mine. Source: U.S. Environmental Protection Agency.

Elizabeth Mine pollution was addressed through environmental cleanup. Public concern over pollution led to the environmental movement of the late 1960s. The U.S. Environmental Protection Agency was established in 1970, and in 1980 Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act, or "Superfund," which allows the EPA to provide funding or take enforcement actions to clean up sites that could harm people or the environment. The EPA's Elizabeth Mine cleanup project greatly reduced acid and metals releases, leading to dramatic recovery of downstream water quality. Mining also left archaeological sites, buildings, and industrial landscapes, and the EPA addressed cleanup impacts to those historical resources through archaeology, documentation, and public education. ▲

Contaminated water flowing from the Elizabeth Mine 1898 adit (entrance tunnel), 2003. Source: U.S. Environmental Protection Agency.

Aerial view of partially overgrown Elizabeth Mine copper ore mill waste tailings pile looking southwest, 1990s. Source: Strafford Historical Society.

The Copperas Works: 1809–1882

Metallic ore was discovered on Copperas Hill in Strafford in 1793. The ore was good for making iron sulfate, or "copperas." Copperas, as it was known since ancient times, was an important industrial chemical for agriculture, medicine, and leather and textile dyeing. While it is largely forgotten today, by the 1800s one could hardly go a day without encountering something made with it. Making copperas required large factories, and initially colonial America relied exclusively on European sources. Trade was cut during the Revolutionary War and the War of 1812, and the young states developed their own industries. In 1809 New England investors formed the Vermont Mineral Factory Company and built a copperas factory at Copperas Hill. The product was proclaimed "as pure and of as good quality as any heretofore imported" and was so important that company workers were exempt from military duty.

Making copperas was a straightforward process. Iron sulfide ore was mined, heaped, roasted, and leached, creating acidic iron sulfate "liquor" that was boiled in lead-lined vats and then cooled until it crystallized. A testament to Yankee ingenuity, the entire gravity-fed Copperas Hill process operated without mechanical power. From March to November the works employed up to sixty miners and teamsters, and in winter just two men stayed on for upkeep. A small village, including a boardinghouse, store, school, and post office, grew around the factories. The copperas was transported by turnpike and canal boat to Boston, Hartford, and New York City and shipped to Atlantic coastal ports.

The copperas works became an important early American industry. After the War of 1812, cheap copperas flooded American markets. In 1817, company partner Colonel Amos Binney Sr. showed President James Monroe the works, possibly to encourage higher import tariffs. The tariff of 1824 enabled profitability. The company built a second factory, and production peaked at 1,600 tons by the mid-1840s, when the works satisfied 75 percent of U.S. demand for copperas. Construction of the nearby Connecticut & Passumpsic Rivers Railroad in 1848 improved transportation. The Vermont Copperas Company enjoyed prosperity and productivity well into the 1850s.

The copperas works declined after the Civil War ended in 1865. Import tariffs were gradually lowered after 1842, allowing foreign copperas to flood the market. Company ownership changed hands several times after 1867. The Strafford operation was shut down in the early 1880s because of low market prices, high production costs associated with obsolete technology, and competition from new, cheaper sources. Production over 73 years was almost 50,000 tons, making it the largest and longest-operating nineteenth-century sulfide-ore copperas plant in the United States. ▲

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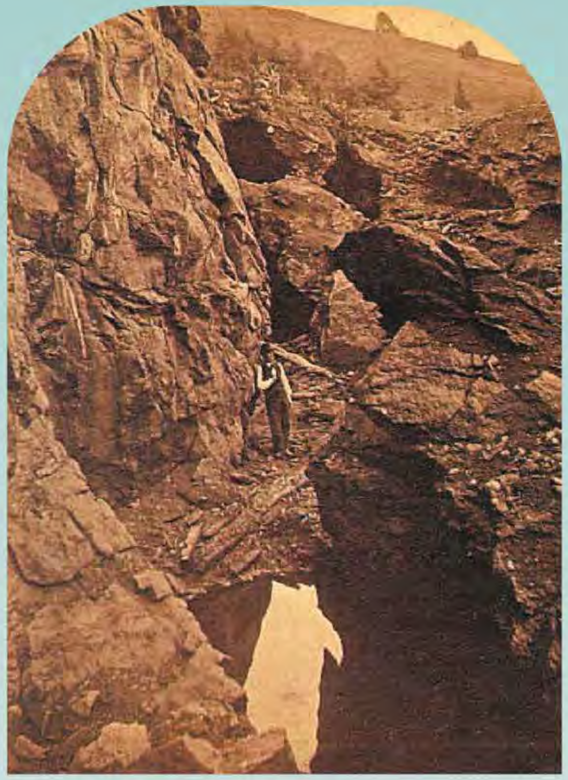
In 1844, geologist Charles T. Jackson, reporting on the Vermont Copperas Company in the Final Report on the Geology and Mineralogy of the State of New Hampshire, *stated that "nearly every man, who wears a black hat, or black cloth of American manufacture, is a patron of these works." Source: Worcester,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

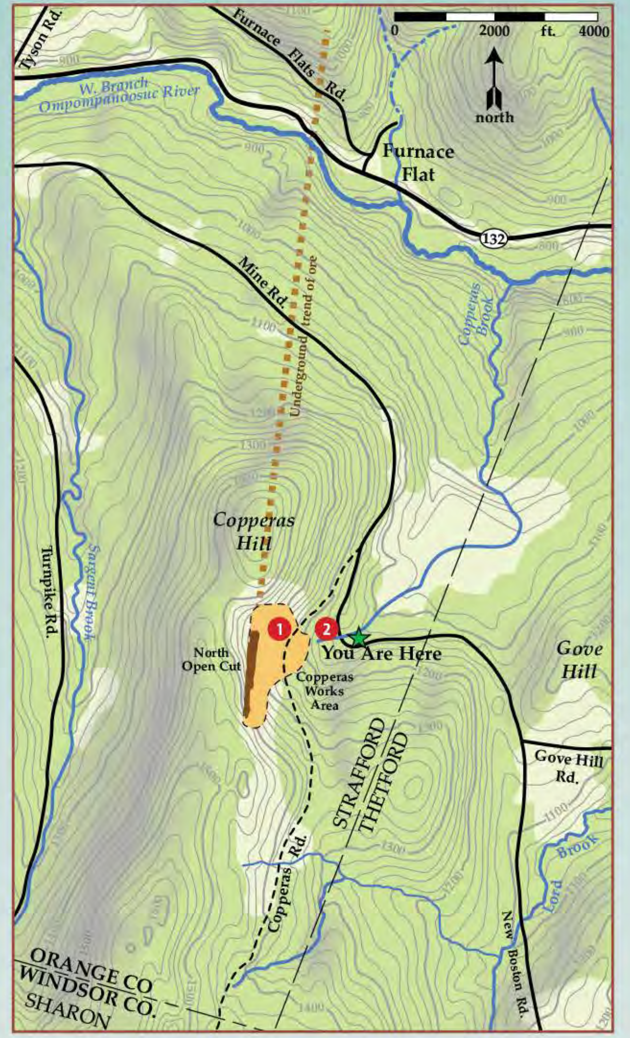
Left: President James Monroe (term in office: 1817–1825), painted by Samuel F. B. Morse, 1819. Source: White House Historical Association. Right: Colonel Amos Binney Sr., Boston shipping merchant and Vermont Mineral Factory Company partner. Source: Strafford Historical Society.

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



Stereo card view of the North Open Cut where the copperas ore was mined, about 1870. Note the man at center for scale. Source: Collamer Abbott Collection, University of Vermont.

Green copperas (iron sulfate) crystals.



Map Key: Numbers in red circles show industrial activity locations and landforms associated with 1809–1882 copperas manufacturing.

1. North Open Cut surface ore mine, and roast beds and heap leach piles area for making weak copperas liquor
2. Factories for boiling copperas liquor and packing the crystallized product

Early Copper Mining: 1830–1930

Copper mining on Copperas Hill began in the 1820s. The Vermont Mineral Factory Company under Colonel Amos Binney's son, Dr. Amos Binney Jr., completed a new adit (tunnel) and shaft to gain better access to the copper ore in 1831. Binney built an ore smelting plant on the Ompompanoosuc River north of the mine at Furnace Flat. In 1833 he hired pioneering chemist Isaac Tyson Jr., of Baltimore, to run the mine. Tyson smelted up to six tons of ore a day in several furnaces, producing a low-grade copper that was shipped to Boston for refining to pure metal. At peak the mine employed 200 men. Tyson achieved several copper industry firsts, including patents for smelting with anthracite coal and hot air blasts. High transportation costs hampered the remote operation, which closed with the financial Panic of 1837. Construction of the nearby Connecticut & Passumpsic Rivers Railroad in 1848 made operations more economical. Smelting resumed at Furnace Flat in the 1850s and was profitable through the Civil War, when copper demand was high.

James Tyson reopened the mine in 1880 and named it after his wife, Elizabeth. James, the son of Isaac Tyson Jr., had new shafts dug north of the copperas works and made low-grade copper in a steam-powered smelter on Sargent Brook at the west foot of Copperas Hill. Tyson moved mining operations northeast in the 1890s, blasted a quarter-mile-long adit to reach more ore, and built a new smelter at the east foot of Copperas Hill. His son, James Tyson Jr., eventually took over. With the help of metallurgist William Glenn, they made higher-grade "pig" copper and developed a new type of furnace lining, which was adopted throughout the smelting industry. Low copper prices and high transportation costs forced Tyson to stop operations in 1902.

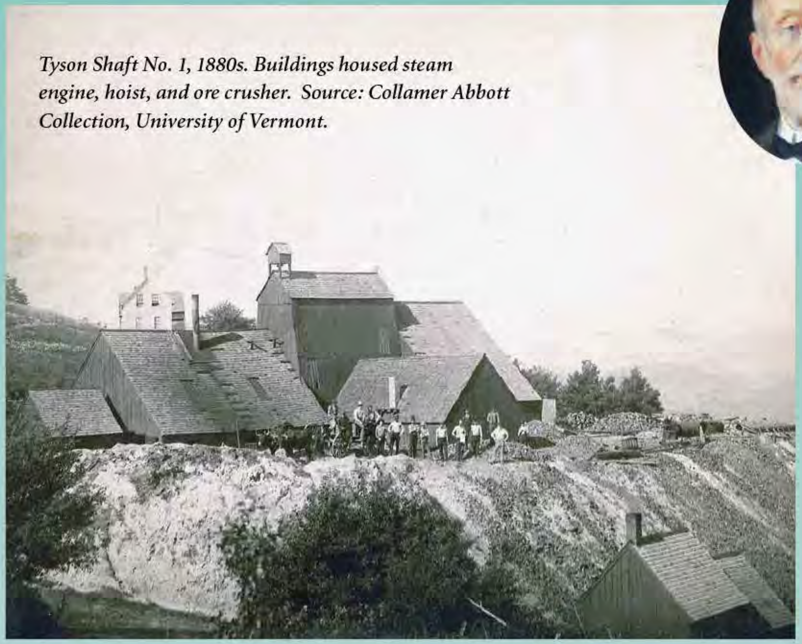
Elizabeth Mine operators kept up with scientific progress. While demand for copper for communication, construction, and power industries grew in the early twentieth century, rich ore deposits were running out. New methods emerged for processing low-grade ores, and several ventures applied them at the Elizabeth Mine. Zinc industry magnate August Heckscher's Vermont Copper Corporation modernized and electrified the mine just prior to World War I, but operations were plagued by explosions and fire. In the late 1920s the National Copper Corporation discovered additional Copperas Hill ore reserves that could be efficiently separated with new technology. All told, the mine produced about 10.5 million pounds of copper metal in the century before the Great Depression of the 1930s. ▲

Three Generations of Tysons

Isaac Tyson Jr. (1792–1861). Elected to the Mining Hall of Fame in 1996. Source: Strafford Historical Society.

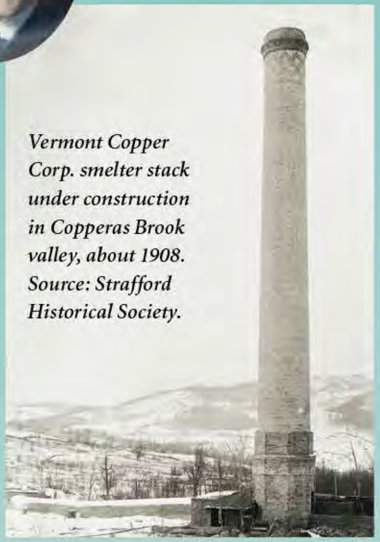
James Wood Tyson (1828–1900), Isaac Tyson Jr.'s son. Source: Webb L. Nimick Collection.

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



Tyson Shaft No. 1, 1880s. Buildings housed steam engine, hoist, and ore crusher. Source: Collamer Abbott Collection, University of Vermont.

Portrait of August Heckscher by Penrhyn Stanlaw, 1925. Source: Heckscher Museum, Huntington, New York.

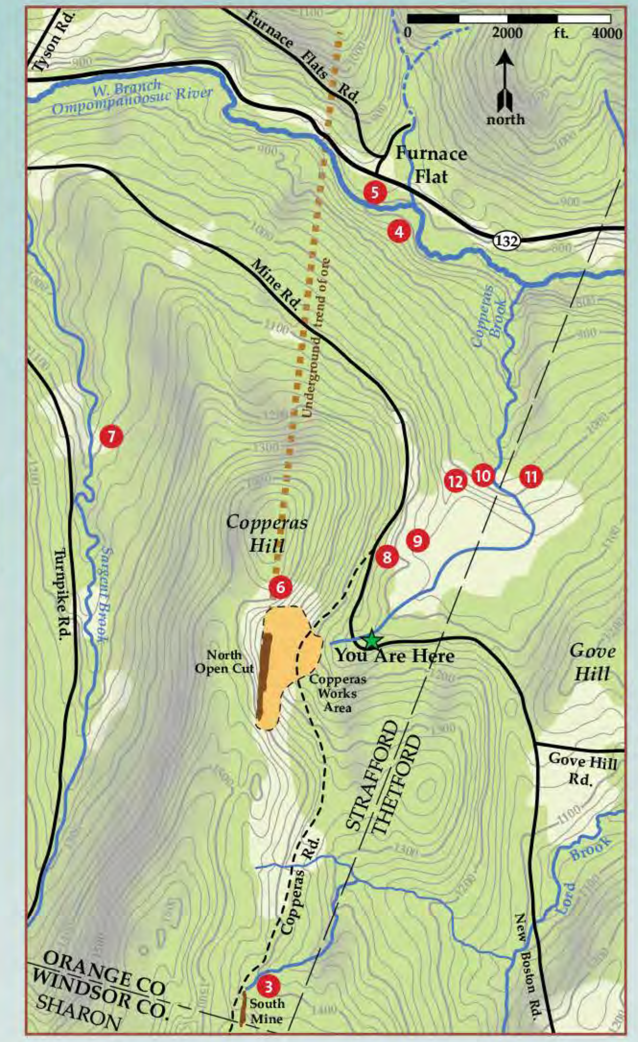


Vermont Copper Corp. smelter stack under construction in Copperas Brook valley, about 1908. Source: Strafford Historical Society.

Elizabeth Mining Company workers, 1880s. James Tyson Jr., second row, second from right. Source: Strafford Historical Society.

Map Key: Numbers in red circles show industrial activity locations and landforms associated with 1830–1930 copper mining and smelting.

3. Limited pre-Civil War copper mining
4. Vermont Mineral Factory Company copper smelting at Furnace Flat (south bank), 1829–1839
5. Copper smelting at Furnace Flat (north bank), 1854–1884
6. Tyson's Elizabeth Mining Company Shaft 1 and Shaft 2, 1881–1890
7. Elizabeth Mining Company copper smelting at Sargent Brook, 1882–1884, 1888–1890
8. Elizabeth Mining Company 1898 adit (used until 1958)
9. Elizabeth Mining Company mill, intermittent copper ore milling, 1898–1930
10. Elizabeth Mining Company copper smelter, 1898–1902
11. Vermont Copper Corporation copper smelter, 1908–1909
12. Vermont Copper Corporation copper smelter, 1916–1919



Copper for War and Peace: 1942–1958

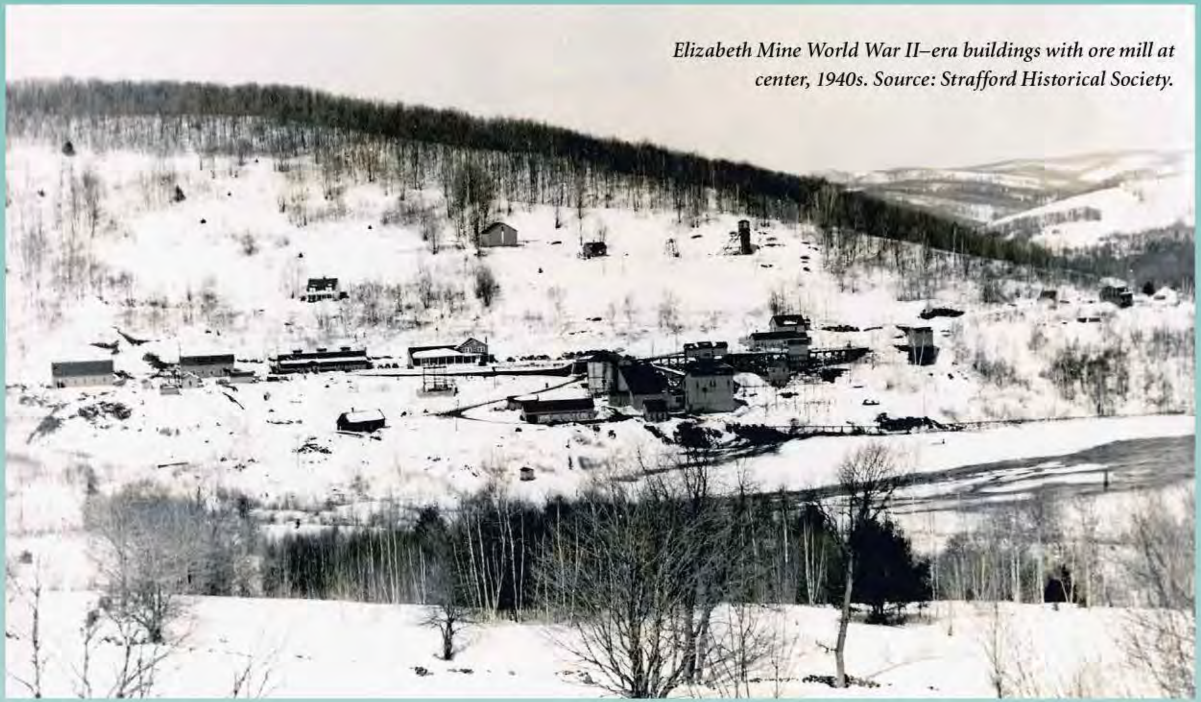
The Elizabeth Mine reopened after U.S. entry into World War II. Vermont's War Production Board and Governor Stanley Wilson organized the Vermont Copper Company Inc. in April 1942 to reopen the Elizabeth Mine to support wartime copper demand. Workers enlarged tunnels for an underground electric railroad and built a new ore-processing mill and support facilities. Mining to fill U.S. government orders began in late 1943. The mill made a copper ore concentrate trucked on then-new Vermont Route 132 to Pompanoosuc Station on the Connecticut River for rail shipment to Long Island, New York, for smelting to metallic copper. Mine employees came from surrounding towns and western U.S. and Canadian mining districts, and enjoyed flexible schedules and high wages.

After World War II, the Elizabeth Mine became profitable and productive. In 1948 a new vertical shaft reached ore deposits extending to the north. The mine made its first profit in 1949, and the U.S. Reconstruction Finance Corporation funded expansion. In 1950, surface mining began at the South Open Cut, and copper output reached 7 million pounds. Sulfur-bearing waste was sold to the Brown Paper Co. of Berlin, New Hampshire, for wood pulp processing. Discarded ore mill waste tailings began to fill the Copperas Brook valley.

The Elizabeth Mine went from "boom to bust" in the 1950s. The mine profited from U.S. government contracts and high copper prices during the Korean War. Appalachian Sulphides Inc. purchased the mine in 1954, when production peaked above 8.5 million pounds and employment reached a high of 220 workers. Profits rose over $1 million in 1955, but the following year copper prices fell and the ore began to run out. Appalachian Sulphides knew the end was near and invested in the historic Ore Knob copper mine in North Carolina. The last chapter in the long history of South Strafford mining ended in 1958, when Appalachian Sulphides closed the Elizabeth Mine and moved equipment to Ore Knob. When the Elizabeth Mine closed, Strafford lost a major employer.

The Elizabeth Mine was an important New England mine. During the 1950s, it was among the top 20 copper producers in the United States. When mining ended, the underground workings stretched 7,800 feet, passing under and north of the Ompompanoosuc River. The Elizabeth Mine yielded 91 million pounds of copper during its mid-twentieth-century revival, with a lifetime output of just over 100 million pounds. ▲

Excavating copper ore from the South Open Cut, early 1950s. Source: Strafford Historical Society.

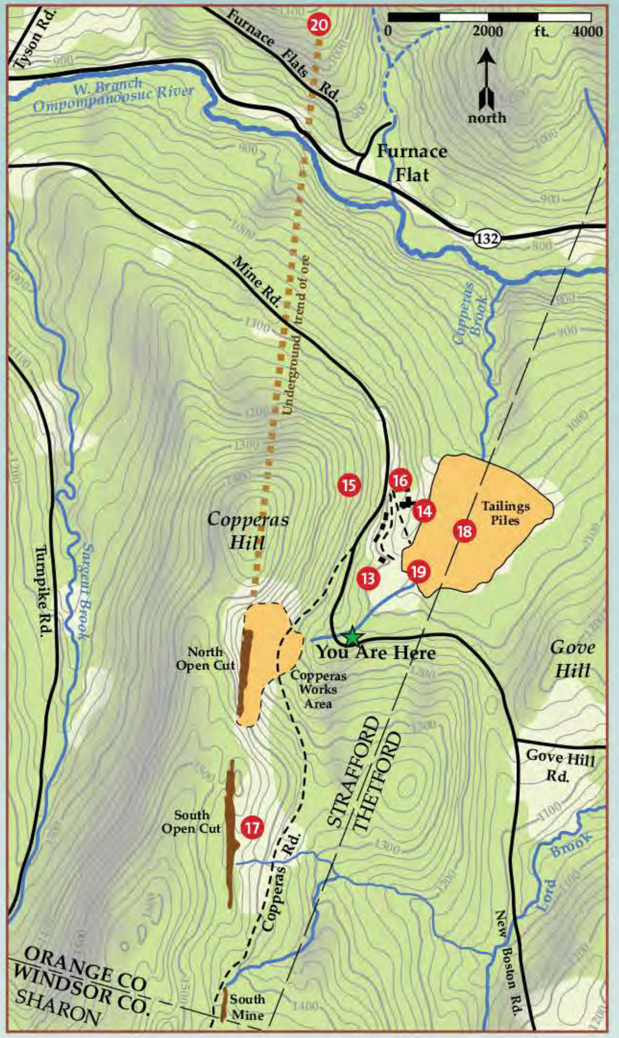


Elizabeth Mine World War II–era buildings with ore mill at center, 1940s. Source: Strafford Historical Society.

Miners pose at the 1898 adit during the World War II era. Source: Strafford Historical Society.

Map Key: Numbers in red circles show industrial activity locations and landforms associated with 1942–1958 copper mining.

13. Vermont Copper Company / Appalachian Sulphides Inc. ore mill and support buildings complex, 1943–1958
14. Vermont Copper Company / Appalachian Sulphides Inc. copper ore processing mill, 1943–1958
15. Vermont Copper Company / Appalachian Sulphides Inc. 1948 shaft
16. Vermont Copper Company / Appalachian Sulphides Inc. 1948 adit
17. South Open Cut, surface mining, 1950–1953
18. Copper ore mill tailings pile 1, 1943–1958
19. Copper ore mill tailings pile 2, 1951–1958
20. Northernmost extent of underground mining, 1958



Impacts and Cleanup: 1958–2015

Nearly 150 years of mining left environmental impacts at the Elizabeth Mine. The copperas works waste piles were releasing metals including cadmium, cobalt, copper, and zinc into the environment, and soil at the copperas factory sites contained high amounts of lead. The 1943–1958 copper ore mill tailings pile was draining iron and sulfuric acid. Metals and acidity in water from the mine site were affecting aquatic life in Copperas Brook and the West Branch of the Ompompanoosuc River.

The Elizabeth Mine became a "Superfund" site and was successfully cleaned up. The U.S. Environmental Protection Agency declared the mine a Superfund site in 2001, making it eligible for funding for study and cleanup. The EPA's cleanup solution was to combine all contaminated rock and soil on the existing copper ore mill tailings pile area in front of you and isolate it from air and water. Work was completed in phases between 2003 and 2015. A small army of large dump trucks moved waste from the copperas works, South Mine, and South Open Cut to the pile. The EPA graded the material, capped it with plastic sheeting to block water flow, and planted grass over it. Trenches were built to divert Copperas Brook around the pile. The cleanup was successful. Levels of acid and metals in water from the mine site are dramatically lower, including a 95 percent reduction of iron. Insect life important to fish populations in Copperas Brook and the West Branch of the Ompompanoosuc River has recovered.

The Elizabeth Mine's history was recognized and documented. The mine site was determined eligible for listing in the National Register of Historic Places in 2001. The EPA addressed cleanup impacts according to the National Historic Preservation Act, ensuring proper documentation and preservation of the most important historic features. The site was thoroughly recorded in written history and photographs. Archaeologists excavated the copperas factories, and the foundations were highlighted for public viewing along Mine Road to your left. The World War II ore mill foundations were preserved in place to interpret their function. The local community, particularly the Strafford Historical Society, strongly supported preservation efforts and provided invaluable support.

The Elizabeth Mine's industrial landscape was compelling, but temporary. The unreclaimed mine site was evidence of a remarkable part of New England industrial history. The reclaimed landscape is different, but just as dramatic as the one it replaced. The Elizabeth Mine site remains a place to learn about our industrial past, its impact on the present, and explore possibilities for the future. ▲

These panels were completed in collaboration with the Strafford Historical Society to fulfill an agreement among EPA, VT Division for Historic Preservation and VT Department of Environmental Conservation to address impacts to historic resources caused by the cleanup. Panels prepared by Milestone Heritage Consulting, subcontractor to Nobis Engineering, Inc., for U.S. Army Corps of Engineers to support EPA.

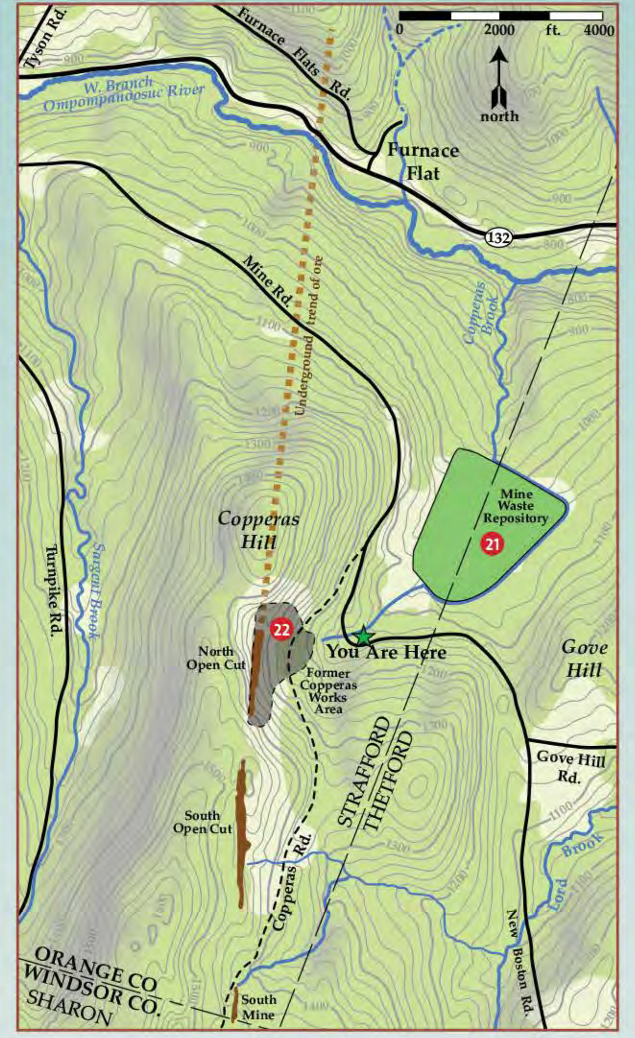
Cleared and preserved World War II copper ore mill foundations, with completed mine waste storage area visible beyond. Source: U.S. Environmental Protection Agency.

Map Key: Numbers in red circles show activity locations and landforms associated with the 2000–2015 EPA Superfund cleanup.

21. EPA Superfund cleanup waste repository: site-wide mine waste consolidated and capped on former copper ore mill tailings pile area
22. EPA Superfund cleanup: copperas works area waste removed and consolidated and capped at waste repository

Archaeologist mapping part of the excavated floor of the lower copperas factory on Mine Road, 2010. Source: U.S. Environmental Protection Agency.

Elizabeth Mine capped waste area at the 1943–1958 copper ore mill tailings pile, looking southwest, 2012. Source: U.S. Environmental Protection Agency.



The Lower Copperas Factory

The Vermont Mineral Factory Company in 1809 built the first of several factories at the sharp bend in Mine Road to make the important iron sulfate chemical copperas. In 1832 the company boasted that its product was used "in every state of the Union, and almost every family, but principally by the manufacturers of woolens and cottons, hatters, and dyers." Annual production peaked at 1,600 tons in the 1840s, when the company claimed to make 75 percent of copperas used in the United States. The copperas was produced in two factories, each 267 feet long by 94 feet wide. The factories were abandoned when the works closed in the early 1880s. Understanding the Elizabeth Mine's history and significance helped shape the U.S. Environmental Protection Agency's Elizabeth Mine "Superfund" cleanup and ensured proper documentation and preservation of the mine's most important features. ▲

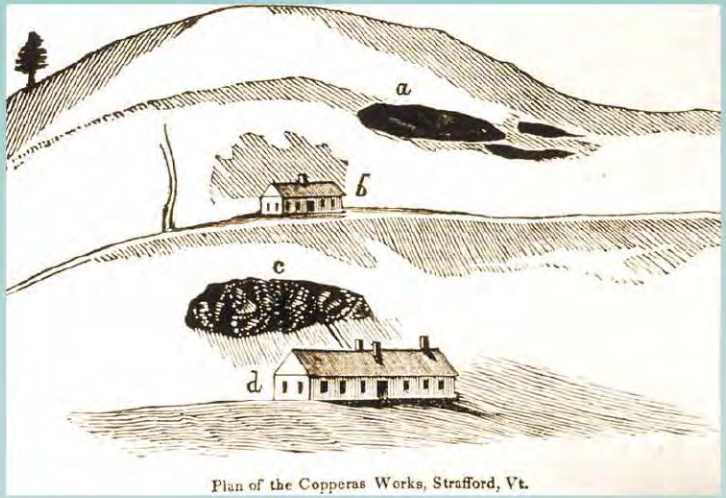
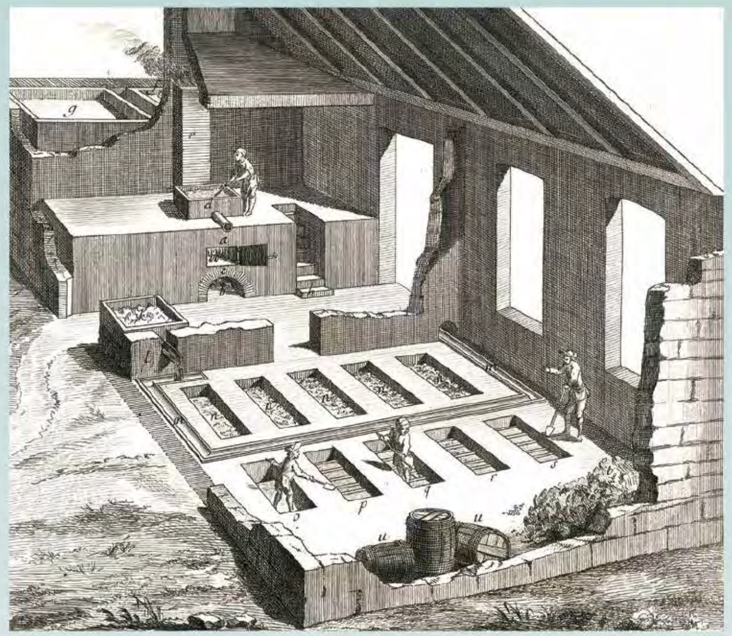


Illustration of the Strafford copperas works, 1844. The ore mine was near the top of the hill at a. Ore was roasted at b, leached with water at c, and copperas crystals made in the factory at d. The bowl-shaped hillside funneled the copperas "liquor" by gravity to the factories. The process concentrated acid and metals and used lead-lined vats, making the most historically significant area of the mine site the most contaminated one. Source: Charles T. Jackson, Final Report on the Geology and Mineralogy of the State of New Hampshire, *1844.*

Archaeologists unearthed this wrought-iron ladle bowl at the lower copperas factory. It was found in an area that included a small furnace, tools, and lead fragments that was identified as a workshop for repairing the lead-lined copperas boilers. Source: U.S. Environmental Protection Agency.



Eighteenth-century French copperas factory illustration showing process from left to right: Weak copperas liquor was stored in outdoor vats and boiled in an elevated furnace inside the factory. Once concentrated it was poured off to cool and settle in a large vat. Then it was flowed into rows of vats to crystallize, and packed in barrels for shipment. Source: Denis Diderot, Encyclopedia or a Systematic Dictionary of the Sciences, Arts and Crafts, *1751–1772. Dover Publications Inc.*

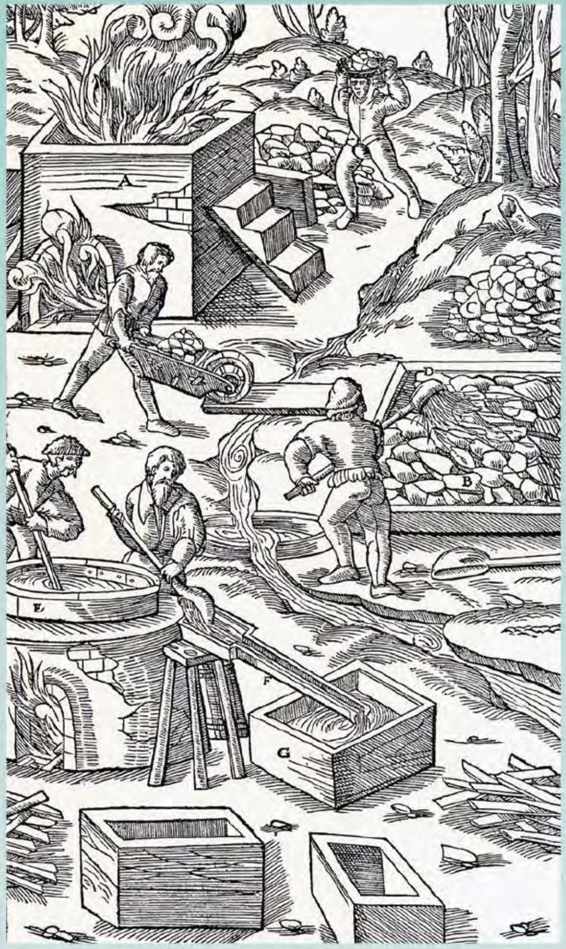
Left: Mine Road looking west in the 1890s, with the abandoned upper copperas factory at center and the ore mining, roasting, and leaching area behind it. Source: Strafford Historical Society.

Below: Mine Road looking west in 2009. The EPA removed lead-contaminated soil, reconstructed the road and Copperas Brook channel, and marked the copperas factory sites for public viewing, with a layer of rounded stone matching the original ground contours. Source: U.S. Environmental Protection Agency.

Archaeologists digging with hand tools and a small backhoe documented the workings of the copperas factories as part of the site cleanup. The brick pit in foreground is part of a copperas cooling and settling vessel found at the lower factory in 2009. Source: U.S. Environmental Protection Agency.

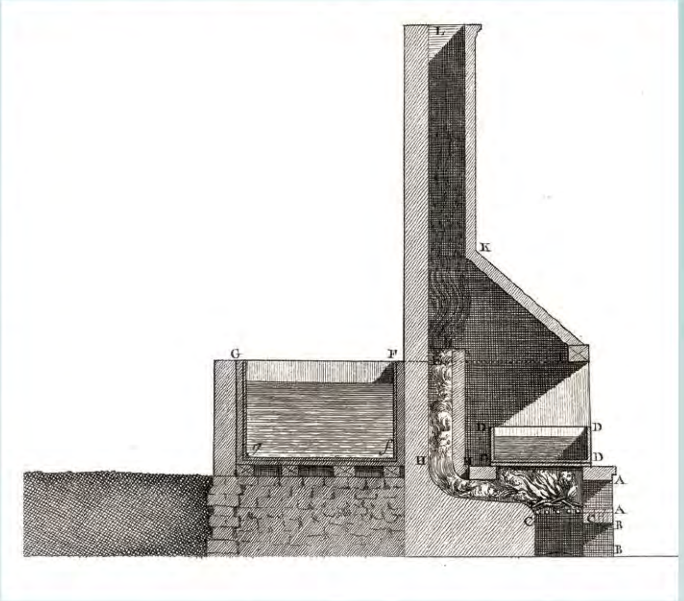
The Upper Copperas Factory

The upper copperas factory was one of at least six that the Vermont Mineral Factory Company and its successors built on Copperas Hill starting in 1809 to boil and crystallize the copperas liquor made at the ore roast beds and leaching piles on the hillside above. Wet soil, heavy masonry vats, and hot sulfuric acid gases slowly damaged the timber-frame buildings, which were rebuilt several times. The vat linings and plumbing were made of lead to resist the corrosive copperas liquor, which was as strong as modern car battery acid. The U.S. Environmental Protection agency recognized that the copperas works was a significant historic industrial site, but one with highly contaminated soil. As part of the mine cleanup, archaeologists documented the upper factory, and the EPA marked the location with a layer of rounded stones. ▲



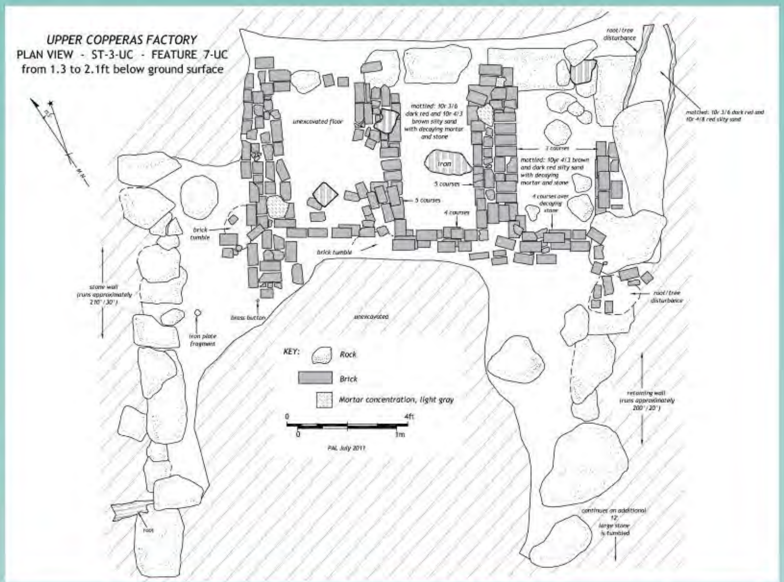
A sixteenth-century German print showing key copperas-making steps. At top, a miner carries ore to a chamber for roasting. At center, miners move roasted ore to a leaching heap and sprinkle water on it to make weak copperas liquor. At bottom they concentrate the liquor in a boiler and tap it into a vat to cool and settle before crystallizing. Source: Georgius Agricola, De Re Metallica, *1556. Dover Publications Inc.*

Naturally formed weak copperas found in waste material at the copperas works area before the Superfund cleanup. Water runoff from the area included acid and metals generated by this kind of mine waste. Source: U.S. Environmental Protection Agency.



Eighteenth-century print of a cross-section through a typical copperas boiler. Weak copperas liquor was transferred from the reservoir at left to lead-lined boiling vat D at right. The air draft from the opening B fed the fire on grate C, and heat and smoke flowed through flue H and up chimney L. Boiling concentrated the dissolved iron and sulfuric acid mixture before it was poured out to cool and crystallize. Source: Denis Diderot, Encyclopedia or a Systematic Dictionary of the Sciences, Arts and Crafts, *1751–1772.*

The brick floor of this copperas crystallizing vat found by archaeologists at the upper factory in 2009 was particularly well-preserved. Source: U.S. Environmental Protection Agency.

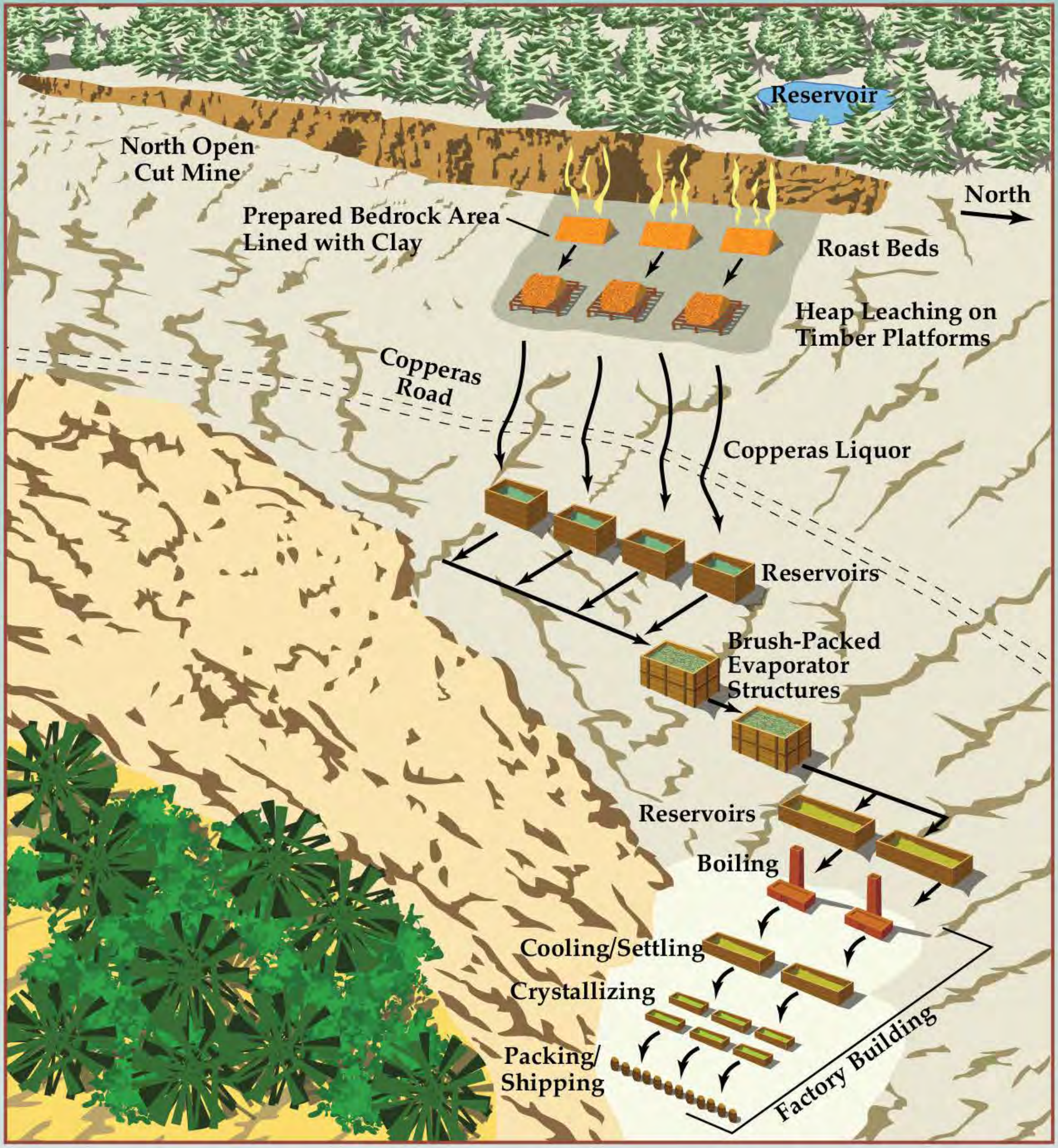


This drawing is a depiction of the remains of the copperas boiler foundations at the upper factory found by archaeologists in 2009. The bricks found here correlate with an 1821 description of the Copperas Hill works: "The bottom is supported by a number of parallel brick walls, placed at a small distance 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.

Archaeologists found well-preserved stone, metal, and wood remains of the three main boiling, cooling/settling, and crystallizing steps of copperas production, which closely matched nineteenth-century written accounts of the Copperas Hill factories. Here archaeologists measure and draw the remains of brick-lined copperas vessels and a network of support timbers at the upper copperas factory, 2010. Source: U.S. Environmental Protection Agency.

The Copperas Works

The Vermont Mineral Factory Company and its successors made the important iron sulfate chemical called copperas on Copperas Hill in South Strafford from 1809 to 1882. The bowl-shaped hillside allowed operation of a cascading, gravity- and water-fed system that ran for over seventy years without need for animal or mechanical power. The process began outdoors high on the hillside and was completed inside barn-like factory buildings at the bottom of the hill near Mine Road. ▲



Schematic illustration of how the copperas-making process was generally arranged on Copperas Hill (not to scale).

ON THE HILLSIDE

Mining

Miners blasted iron sulfide ore from a long, narrow pit near the top of the hill and broke it into apple-size lumps.

Roasting

Workers next heaped the ore over wood and set fire to it, which ignited the sulfur in the ore. They tended the smoldering heaps for several months, sprinkling them with water from a nearby reservoir to control the temperature. Heat and water helped form sulfuric acid, which decomposed the ore and formed weak copperas.

Leaching

After a year of roasting, the ore was ready for leaching. Workers piled roasted ore on timber platforms on an area of bare rock sealed with clay. They sprinkled water on the heaps, leaching out weak copperas "liquor" that ran through trenches cut in the rock to storage reservoirs.

Evaporating

After the weak liquor settled, it was sprinkled through tall sheds full of tree branches, which concentrated it slightly by evaporation before it was sent to the factories.

IN THE FACTORIES

Boiling

Factory operators boiled batches of weak copperas liquor in wood-fired, brick furnaces lined with lead to withstand the concentrated sulfuric acid. They added scrap iron to raise the iron content of the liquor.

Cooling/Settling

The workers next tapped the concentrated copperas liquor, strong as car battery acid, into lead-lined vats to cool and let impurities settle.

Crystallizing

In the final step, the workers poured the liquor into cement-lined vats. Over a week's time, bright emerald-green copperas crystals formed on branches or rods hanging in the liquor, similar to how rock candy is made.

Packing

Factory workers packed the copperas in wooden barrels and casks, which teamsters then took ten miles by horse-drawn wagon to the railroad on the Connecticut River at Pompanoosuc.

Green copperas (iron sulfate) crystals.

The preceding description was drawn from an account of the copperas works by R.H. Duncan that appeared in Abby Maria Hemenway's 1871 *Vermont Historical Gazetteer.* ▲

OCEAN TO MOUNTAIN: ELIZABETH MINE ORE

The Elizabeth Mine is located in the Gile Mountain Formation, which is a geologic unit within Vermont's eastern Green Mountains, a part of the Appalachian Mountains. The Appalachians, stretching from Alabama to eastern Canada, were formed by a series of orogenies—mountain-building continental collisions—that occurred between about 480 million and 260 million years ago. Once as tall as the Rocky Mountains, Vermont's mountain ranges eroded to their present heights over hundreds of millions of years, exposing a rich variety of building stones, metals, and industrial minerals, including granite, marble, slate, verde antique serpentinite, copper, iron, asbestos, and talc.

Vermont's Orange County copper mines are examples of an important type of metallic ore deposit. These ores formed on the seafloor where water circulated through broken rock heated by shallow magma, resulting in submarine hot springs. These types of sulfide ores form worldwide and were also mined in the eastern United States at locations including Ducktown, Tennessee; Ore Knob, North Carolina; Great Gossan Lead, Virginia; Rowe, Massachusetts; and Blue Hill, Maine. Sulfide ores can contain copper, lead, zinc, and other metals, although only copper was produced at the Elizabeth Mine. Sulfide ore mine waste exposed to weathering has the potential to create acid water and metals contamination.

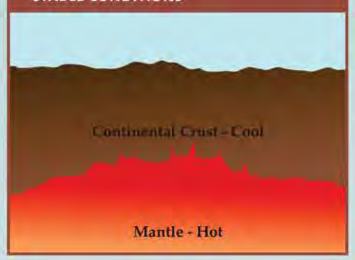
Weathered dark copperas ore in piles from roasting and heap leaching and lighter copper mining waste rock on Copperas Hill before the cleanup, 2010. Source: U.S. Environmental Protection Agency.

The remarkable expanse of exposed bedrock on Copperas Hill is the result of historic industrial activity and recent environmental cleanup. Between 1809 and 1882, copperas miners dug iron sulfide ore from an open trench at the top of the slope, roasted it in heaps, and leached it with water to make weak copperas "liquor." Miners removed the soil, plugged cracks in the rock with clay, and cut trenches, turning the hillside into a giant funnel directing the copperas liquor to the factories at the bottom of the hill. Later, multiple phases of copper mining left more waste on top of the copperas ore piles. The U.S. Environmental Protection Agency identified the colorful eroded waste as a major source of acid mine drainage and metal contamination. In 2010, the EPA removed the waste and relocated it for onsite disposal, exposing the bedrock once again. The bare rock contains crystals of minerals characteristic of metamorphosed seafloor rocks, including large garnets and amphiboles. ▲

ELIZABETH MINE ORE FORMATION

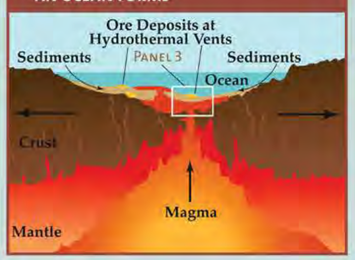
FORMATION OF SEAFLOOR SULFIDE ORE DEPOSITS OF THE TYPE INCLUDING THE ELIZABETH DEPOSIT

1. BEFORE ORE FORMATION: STABLE CONDITIONS



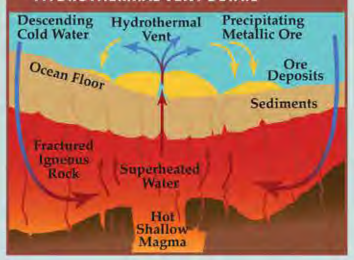
Silurian Period and earlier; approximately 430 million years ago and older. Conditions are stable, with thick continental crust riding on the hot mantle. (Illustrations are schematic and are at different scales.)

2. CONTINENTAL CRUST SPREADS APART: AN OCEAN FORMS



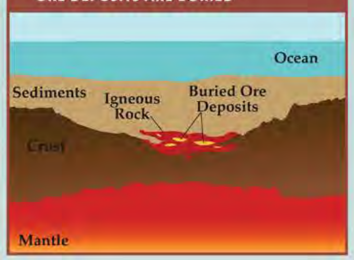
Early Devonian Period; approximately 415 million years ago. Molten rock rises up through the mantle into the crust. The crust splits, thins, and pulls apart. Seawater fills the resulting basin. Volcanic rocks spread out onto the seafloor. The volcanic heat and seawater begin to interact to form metallic sulfide ore deposits at hydrothermal vents. Continental rocks erode and bury the seafloor rocks in sediments.

3. ORES ARE DEPOSITED: HYDROTHERMAL VENT DETAIL



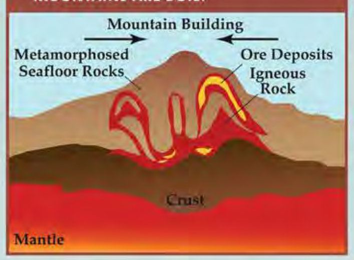
Early Devonian Period; approximately 415 million years ago. Cold seawater descends through seafloor cracks under great pressure. Water is superheated by hot rocks, leaching out metals and sulfur. Hot, metal-laden water rises through cracks back into the ocean. Metals precipitate from cooling water and are deposited on the seafloor to form metallic sulfide ore deposits.

4. STABLE CONDITIONS RESUME: ORE DEPOSITS ARE BURIED



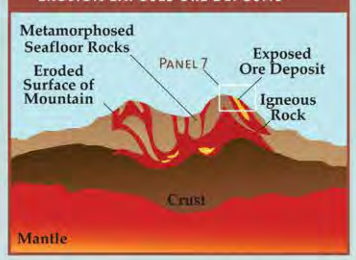
Early Devonian Period; approximately 415 to 400 million years ago. Magmatic and volcanic activity ends. Hydrothermal venting and ore formation stop. Sediments continue to bury the ore deposits on seafloor.

5. CONTINENTAL CRUST CONVERGES: MOUNTAINS ARE BUILT



Early Devonian Period; approximately 400 million years ago. The split continental crust drifts back together. Crust, including igneous and sedimentary rocks and ore deposits, thickens as opposing plates collide, forming mountains. The collision deforms the rocks from their original horizontal configuration into the tilted positions that we see today. Crustal thickening caused the rocks to undergo physical and mineralogical changes due to heat and pressure, a process that geologists call metamorphism.

6. STABLE CONDITIONS AGAIN: EROSION EXPOSES ORE DEPOSITS



Early Devonian Period to present; approximately 400 million years ago to today. Millions of years of erosion wear down the mountains and expose the metamorphic rocks containing the ore deposits. In Vermont, erosion of the Green Mountains exposes the Orange County copper ore deposits exploited by the Elizabeth Mine.

7. COPPERAS HILL: THE ELIZABETH MINE ORE DEPOSIT

East-west section through Copperas Hill, looking north, present conditions. Steeply dipping sulfide ore deposit shown in yellow is oriented parallel to uplifted metamorphosed seafloor host rock beds. The surface open cut, underground vertical shaft and horizontal "adit" (tunnel) show ways miners typically accessed ore for mining. An actual secured adit and shaft are visible from Copperas Road where it crosses the hillside.

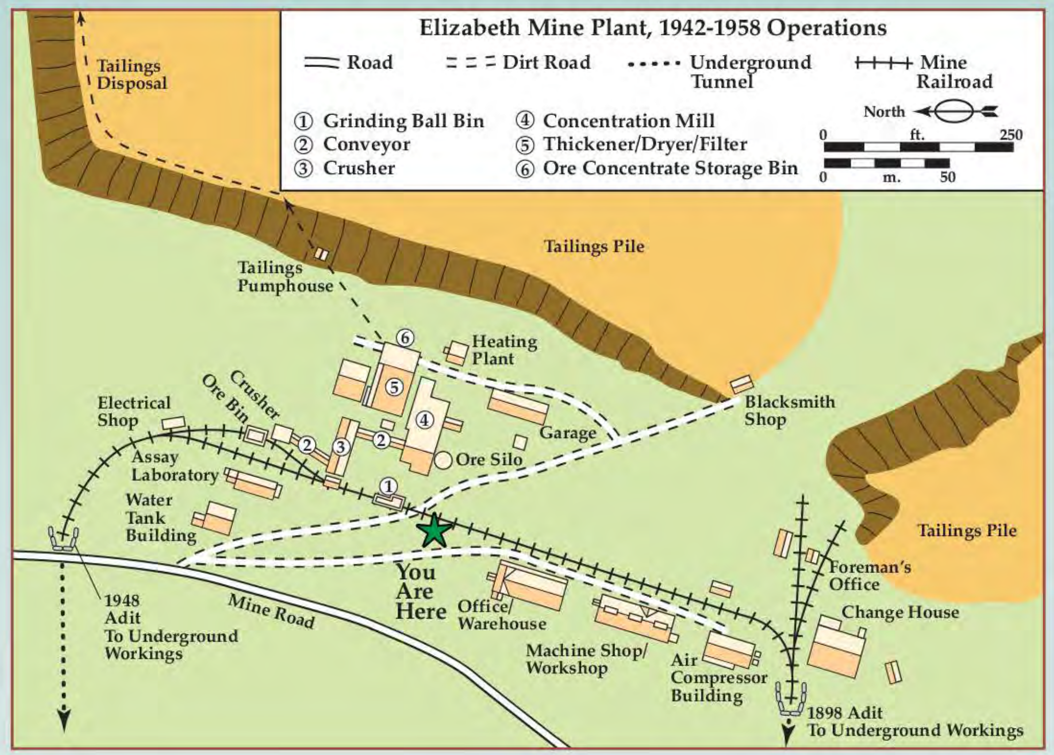
World War II Mine Plant and Tailings Pile

The Elizabeth Mine reopened in 1942 to support World War II copper supply. The Vermont Copper Company constructed a mine complex that was almost self-sufficient. Miners showered and dressed in the change house. The air compressor building supplied air for rock drills, and repairs were made in the machine shop/workshop. The office/warehouse kept things running smoothly and provided spare parts. Mine cars powered by overhead electric wires ran on tracks connecting the two “adit” tunnels, moving ore from underground to the concentration mill. Even though most buildings were demolished during the U.S. Environmental Protection Agency’s “Superfund” cleanup, the foundations of many key buildings were preserved in place.

“Froth flotation” ore processing technology increased efficiency. Froth flotation, developed in Australia in the early 1900s, revolutionized the metal mining industry, making previously worthless low-grade ore worth mining. In this process, ore is ground in rotating drums filled with water and steel balls. The mix is stirred in tubs with chemicals to make the ore particles stick to floating bubbles, and unwanted rock waste sinks to the bottom. The concentration mill, built on a hillside to take advantage of gravity and water flow, processed up to 750 tons of ore a day using flotation equipment. Of the 100 million pounds of copper produced at the Elizabeth Mine from 1830 to 1958, 90 percent of it was processed using flotation. Several million cubic yards of fine, sandy waste “tailings” were pumped from the mill, forming a massive flat-topped pile in the Copperas Brook valley.

The last phase of activity was environmental cleanup from 150 years of mining. Sulfuric acid and metals ran from the mine waste, adversely impacting the ecology of Copperas Brook and the West Branch of the Ompompanoosuc River for over forty years. The EPA’s solution was to build a cover system to isolate the waste from air and water. Trenches were constructed to reroute Copperas Brook around the tailings, which along with waste relocated from other parts of the mine, were graded and covered with a plastic membrane to block water infiltration. The plastic was covered with two feet of soil and planted with grass, resulting in the current appearance. The cover system was very successful in reducing the iron leaching from the tailings and the release of metals from the waste rock. For the first time in decades, the sections of the West Branch of the Ompompanoosuc River downstream of the mine now support a healthy biological community. ▲

Left: A miner poses with an electric mine locomotive, 1950s. Source: Strafford Historical Society. Below: Elevated wood troughs for pumping copper mill waste onto the tailings pile, 1950s. Source: Strafford Historical Society.

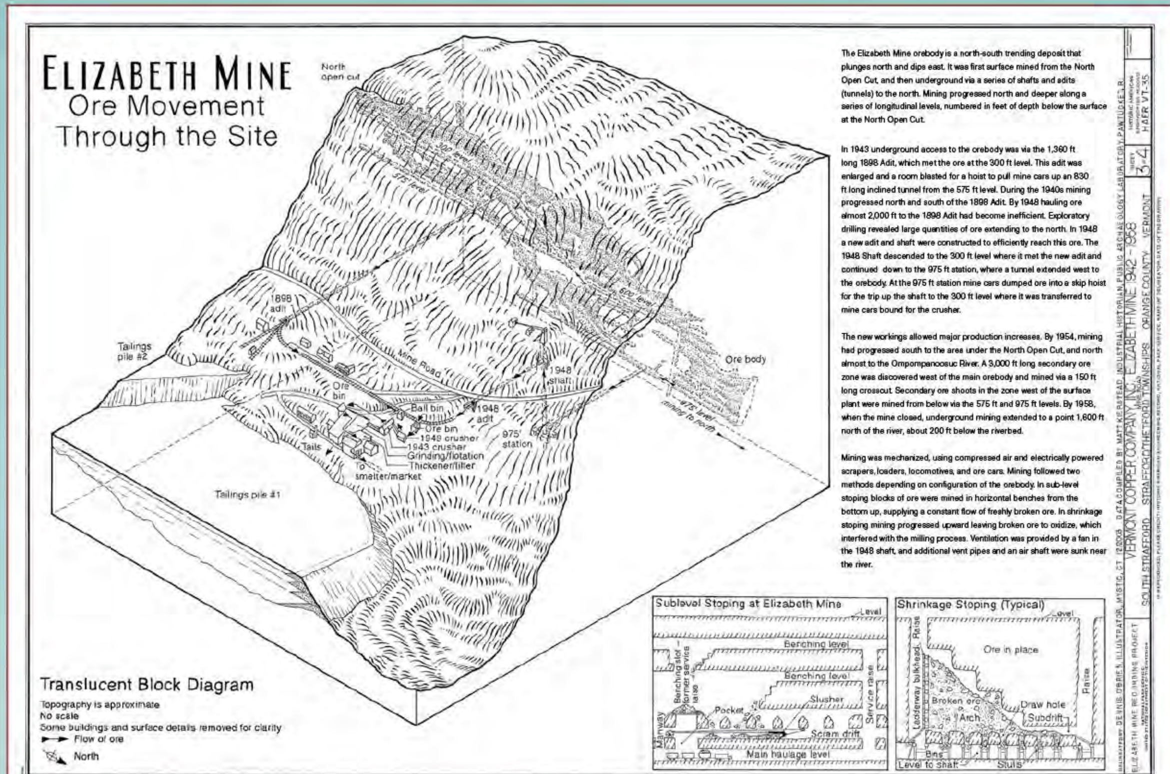


World War II–era copper ore storage silo and Concentration Mill, with ore mill tailings pile beyond, 1950s. Source: Strafford Historical Society.

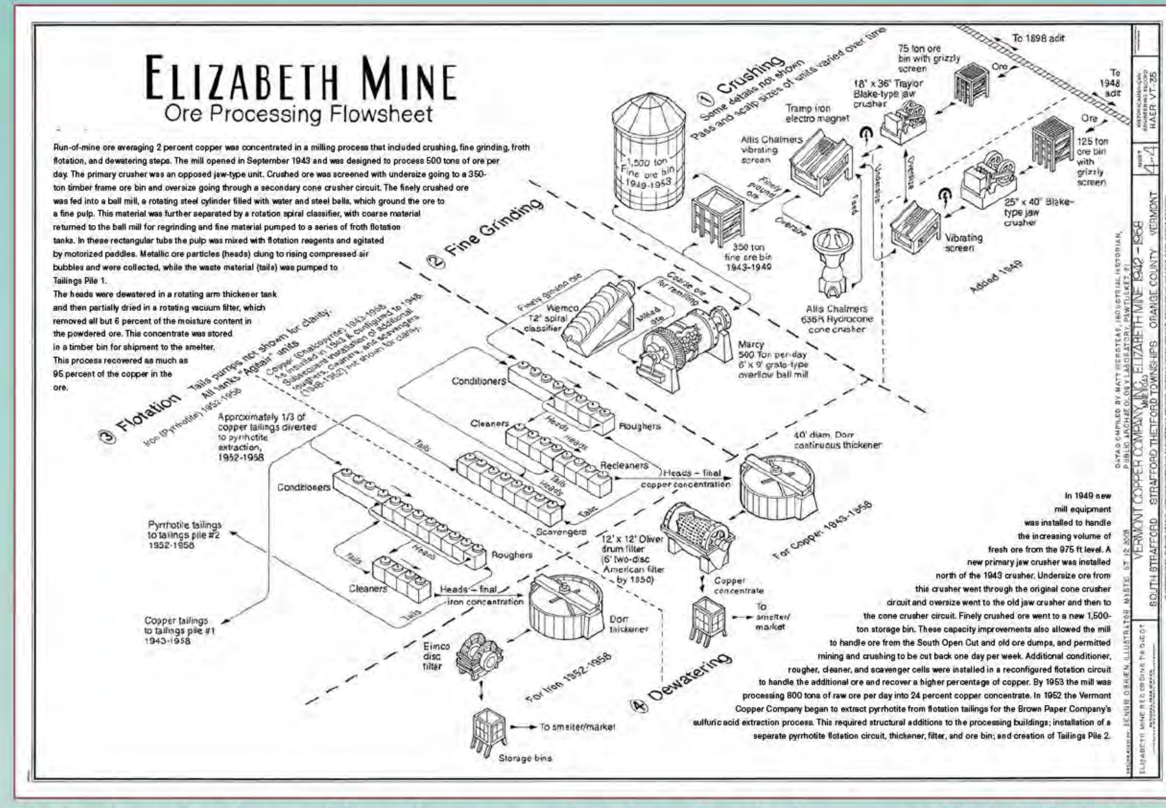
Miners drilling rock underground, World War II era. Source: Strafford Historical Society.

Ore Mining and Milling 1942–1958

Elizabeth Mine 1942–1958 operations involved extensive underground workings, sprawling surface facilities, and complex ore-processing equipment. These elements were recorded to National Park Service / Historic American Engineering Record standards, including photographs, a written report, and four technical drawings, all placed in the U.S. Library of Congress as part of the U.S. Environmental Protection Agency's historic resource documentation efforts. Two of the documentation drawings are shown below. ▲

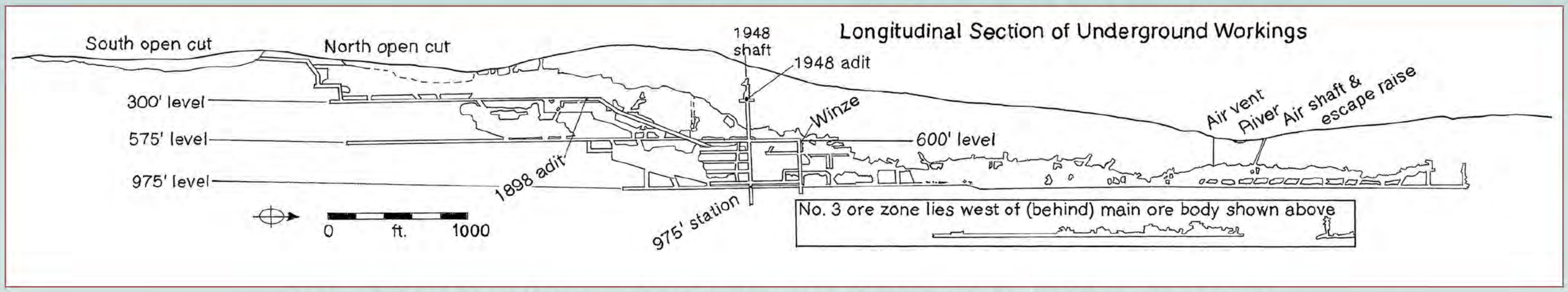


This translucent block diagram shows the Elizabeth Mine's mid-twentieth century surface plant and mine railroad connections to the underground workings, and the shape of the mine's orebody. The drawing includes two cross-section diagrams that show the primary methods used to systematically remove the ore.



This flow diagram shows the sequential steps of copper ore processing and waste disposal as they were arranged inside the Elizabeth Mine's World war II-era Concentration Mill. The diagram also shows the additions that were made to the process over time to handle more ore and to extract part of its iron content.

Drawings by Dennis O'Brien Maps & Wayfinding



This diagram, which was included in one of the documentation drawings, shows a longitudinal section through the Elizabeth Mine surface and underground workings, looking west.
Mining activity progressed from south to north (left to right) over the life of the mine. Most of the ore was removed between 1942 and 1958, when mining extended under and north of the West Branch of the Ompompanoosuc River.

From Cleanup to Clean Energy

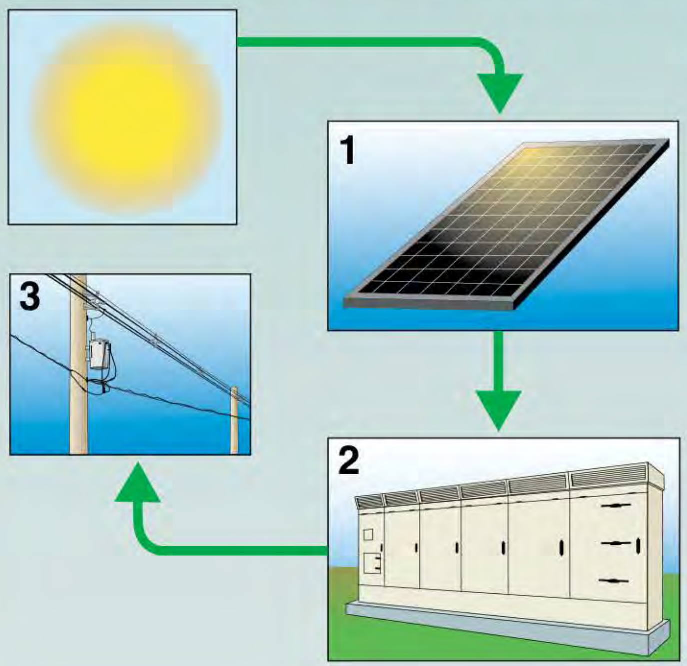
Aerial Photograph Showing Solar Array on Mine Waste Cap

The Elizabeth Mine went from "Superfund" to "Super Solar." The U.S. Environmental Protection Agency designed the mine waste cap water drainage system to promote runoff and to create an open surface area suitable for beneficial reuse. After years of effort by the Strafford Energy Committee, in 2017 a solar energy partnership including Wolfe Energy, Brightfields Development, and Greenwood Energy created *Elizabeth Mine Solar I, LLC* to outfit the mine waste cap with 19,998 photovoltaic, or "solar" panels. This solar panel "array" generates an average of 8.7 million kilowatt-hours (kWh) of electricity each year, enough to power 1,333 typical Vermont homes. In addition, this project helps defray the State of Vermont's mine waste cap maintenance costs for the life of the solar project. Solar panel operation is guaranteed for 25 years, and with proper maintenance, the array could provide power for generations to come.

Clean Energy Reducing Carbon Emissions. Each year, this solar array will offset generation of 7,136 tons of carbon dioxide "greenhouse gas." This is equivalent to the amount of carbon generated by 1,368 fossil fuel-powered passenger vehicles—or the carbon that could be sequestered by 6,128 acres of forest.*

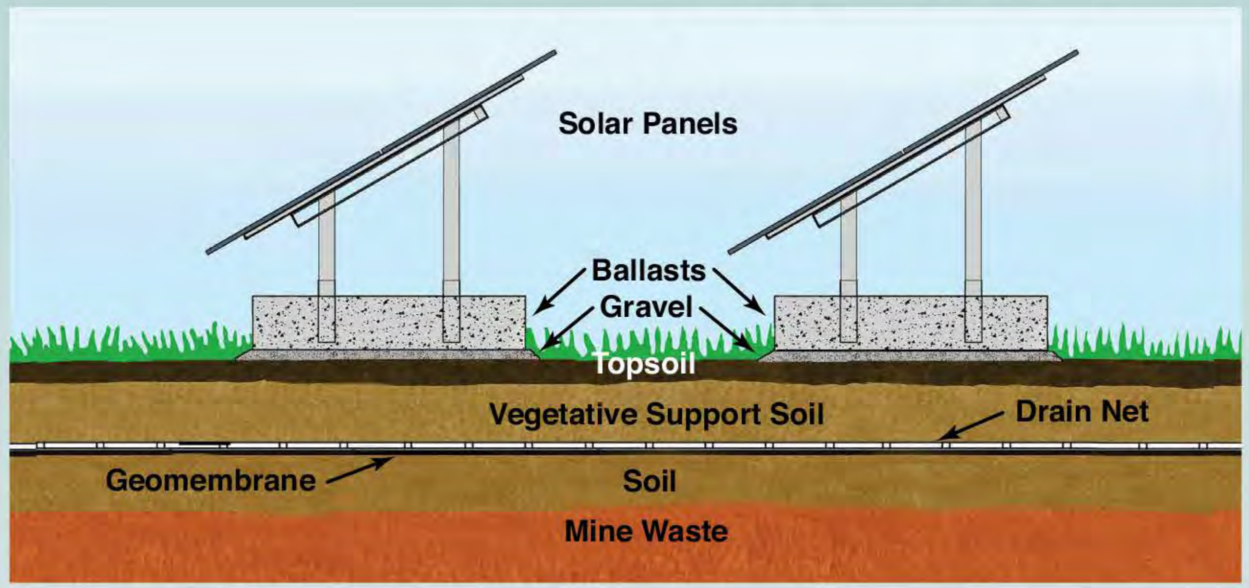
Solar energy has additional benefits. The solar array generates tax revenue for Vermont and the towns of Strafford and Thetford. It is a good neighbor—that creates no pollution!! ▲

* Source: www.epa.gov/energy/greenhouse-gas-equivalencies-calculator



How Solar Works

1. Sunlight falls on high-capacity solar panels during daylight hours. Photon energy from the sun excites electrons in the solar panel material, generating Direct Current (DC) electricity. At the Elizabeth Mine, the maximum potential energy of the entire solar array in full sunlight is 7 megawatts (MW) DC per hour.
2. The DC electricity is then sent to an inverter which converts it into Alternating Current (AC) electricity. At the Elizabeth Mine, the total power output of the inverters is 4.99 MW AC.
3. The low-voltage AC electricity from the inverter is sent to a transformer to step up the voltage for transmission through utility lines to provide power to regional homes and businesses.



Protecting the Cap. The solar panels are mounted on racks held in place by concrete weights or "ballasts." These ballasts are laid on gravel beds so they do not penetrate the protective barrier capping the mine waste below. The layers of soil and buried geomembrane barrier constructed by EPA are designed to drain clean surface water away from the mine waste.