SHENANDOAH-DIVES MILL
(Mayflower Mill)
135 County Road 2
Silverton
San Juan County
Colorado

HAER CO-91
CO-91

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001

HISTORIC AMERICAN ENGINEERING RECORD

SHENANDOAH-DIVES MILL
(Mayflower Mill)

HAER No. CO-91

Location:	135 County Road 2, Silverton, San Juan County, Colorado
Dates of Construction:	1929, 1934-37, 1943-45, 1960-62, 1972-1978, 1985
Present Owner:	San Juan County Historical Society
Present Use:	Mining Interpretive Museum
Significance:	The Shenandoah-Dives Mill is an exceptional example of early twentieth-century American flotation mills. The building is a multi-level, wood-and-metal structure housing an intact collection of equipment that exemplifies flotation-milling practice during the twentieth century.
Historians:	Dawn Bunyak and J. Lawrence Lee, Ph.D., P.E., 2006-2007
Project Information:	The Historic American Engineering Record completed recording of the Shenandoah-Dives Mill during the summer and fall 2005 for the San Juan County Historical Society. Documentation was conducted under the general direction of Richard O'Connor, Acting Manager, HABS/HAER/HALS and Acting Manager, HAER. Dana Lockett, HAER Architect, supervised the project. The recording team consisted of Field Supervisor, Courtney Gunderson; Architect, Michael McDonald; US/ICOMOS interns, Charu Chaudhry (India) and Andreea Milea (Romania); Architectural Technicians, Heather Rusch and Alan Tansey; HAER Photographer, Jet Lowe; HAER Engineer-Historian, J. Lawrence Lee; and Historian, Dawn Bunyak. A State Historical Fund grant from the Colorado Historical Society paid for the project in part. The contents and opinions contained herein do not necessarily reflect the views or policies of the Colorado Historical Society.

CONTENTS

CHAPTER 1: INTRODUCTION

With the imminent depletion of the nineteenth-century world's rich-ore supply, the mining industry faced a severe crisis. Historians Michael Malone and Richard Etulain contend that, "in the wake of the Panic of 1893, precious metals faced a dreary future: the best high-grade veins had, for the most part, been mined out, and silver had lost its primary market when the U. S. government stopped coining dollars."[1] An innovative process known as flotation milling diverted the crisis by providing the most efficient means of mineral recovery from low-grade ores to date. Although metals prices continued to fluctuate, flotation milling kept costs low enough that precious and non-precious metal production remained practical well into the twentieth century.

Ore processing is the extraction of minerals of economic value from rock.[2] After ore has been extracted from a mine, it is crushed and ground to a fine sand or powder to enable the collection of valuable metals in the milling process. Several methods are used to collect or concentrate valuable metals:

- gravity, based on the different specific gravities of metals and waste;
- amalgamation, a mercury-based collection process;
- leaching, the percolation of liquids with affinities for metals through ore; and
- flotation, floating minerals off in a bath of treated water.

From the mill, the concentrate is transported to a smelter for the final processing stage. At the smelter, the concentrate is heated to its melting point to separate any

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[1] Michael Malone and Richard Etulain, *The American West: A Twentieth-Century History* (Lincoln & London: University of Nebraska Press, 1989), 23. For more information on mining's threatened future, refer to Frank R. Milliken's "Introduction" and Charles W. Merrill and James W. Pennington, "The Magnitude and Significance of Flotation in the Mineral Industries of the United States," both found in *Froth Flotation: 50th Anniversary,* D. W. Furstenau, ed. (New York: American Institute of Mining, Metallurgical and Petroleum Engineering Incorporated, 1962), 1-3 and 55-56; and Jeremy Mouat, "The Development of the Flotation Process: Technological Change and the Genesis of Modern Mining, 1898-1911," *Australian Economic History Review* (March 1996), 4 and 6.

[2] Donald L. Hardesty, *The Archeology of Mining and Miners: A View from the Silver State,* Special Publication Series, no. 6, (Ann Arbor, Michigan: The Society for Historical Archaeology, 1988), 18. In his serial publication, although discussing the silver industry, Hardesty provides a succinct and thorough summation of mining technology breaking it down into several subsystems beginning with extraction through the milling processes and transportation to smelter.

impurities and poured into molds, where it cools into ingots that are shipped to the industrial market.

In 1905, a British company, Minerals Separation Incorporated (M.S.I.), retrofitted a mill at Broken Hill, Australia, to test a new process called flotation. The process became a commercial success and eventually spread throughout the industry worldwide. In 1912, the flotation process was introduced to the American mining industry in a Butte and Superior Mill at Butte, Montana. The evolution of the modern flotation process significantly impacted the industry, because flotation efficiently and economically concentrated complex minerals that were practically impossible to treat using earlier concentration methods.

Market forces prompted a major shift from costly, labor-intensive underground mines with 500 to 2,000 tons-of-ore-per-day (tpd) flotation mills to modern, mechanized, open-pit mines and enormous 60,000 tpd mills in the American mining industry. The numbers of miners and laborers needed shrank significantly when large, mechanized equipment was introduced that could do the tasks formerly held by humans. While cost effective, open-pit mines have had a significant environmental impact on the western mining landscape by removing thousands of tons of ore and overburden, along with much native vegetation. Reclamation in recent decades has mitigated some of the resultant erosion and water pollution problems, but residuals from some early sites remain untreated. Underground mines were not immune from pollution problems, but they had less impact on the surface landscape.[3]

A 1998 survey of industrial mills from the early flotation era found only four extant 500-to-2,000-tpd, flotation mills in the United States. During the first half of the twentieth century, industrial mills ranged from 25 tpd to 2,000 tpd, with large mills defined in the 500-to-2,000-tpd range. By the end of the century, large mills could produce between 2,000 and 60,000 tpd. The Shenandoah-Dives Mill is an excellent example of a selective flotation mill displaying the distinctive characteristics of the hard-

[3] Water contaminates come primarily from mine spoils or overburden and mill tailings. Various elements and compounds can leach out into streams and aquifers. While less obvious than for an open-pit mine, an underground mine can significantly impact the landscape as well when the miners cut down surrounding trees for support timbers in the mine, leaving the area unprotected from erosion.

rock milling process in the early twentieth century. Its technical history illustrates well the evolution of flotation milling in the United States and its impact on the twentieth-century mining and milling industry.

CHAPTER 2: DESCRIPTION OF CURRENT CONDITIONS

The Shenandoah-Dives Mill seen today appears almost exactly as it did when operations closed in 1991. Much of the building and equipment dates from its opening in 1929, and as will be noted throughout the report, most major and minor modifications and process changes were documented and are identifiable at the site. The L-shaped mill building is a multi-level structure built to accommodate the processes contained within as well as the topography of the site, which slopes down to the south. The east-west wing measures 345' and the north-south wing measures 262'. The building is truss-timbered framed with either gable or shed roofs of corrugated metal at its various levels. As originally constructed, the mill was clad in Oregon-fir and native timber siding and had a concrete foundation. In 1981, corrugated metal siding was applied to the exterior, although in some areas, the original timber siding can still be seen. The building has a variety of multi-light windows, including stationary nine light, stationary double and triple nine light side-by-side, and nine-over-nine double-hung sash. Over eighty windows originally were installed to light the interior, but only select windows were left open after the 1981 corrugated metal siding installation. Although several metal and frame-sided additions have been added to the main building, the overall lines and shape, as well as the technology, of the mill have remained largely unchanged since its original 1929 construction.[4]

Material entered the building via a tram connecting to the eastern side of the east-west wing of the building. The rod mill, fine ore bin, conveyor, custom-ore bins, and crushing plant are in the east-west wing of the building, allowing gravity to facilitate the movement of material through the plant. The fine ore bin area, as well as the conveyor building and crushing plant, have gabled roofs. The rod mill has a shed roof. The north-south wing includes the fine grind circuit with the Marcy ball mill and reagent deck with shed roof. An addition on the east elevation of the fine grind circuit contains a workshop with shed roof measuring approximately 24'x44'. The workshop was used to maintain machinery within the plant as well as to fabricate equipment for use in the mine. Small, hand-pushed flatcars on tracks set into the floor enabled the movement of heavy items to and within the shop. The aerial tramway transported fabricated or repaired machinery to the mine.

The flotation circuit, amalgamation circuit, and sub-floor conditioning tanks are located in the next section of the north-south wing under a front-gable roofline. The lowest section of this wing houses the thickening area, filter deck, boiler room, and concentration bins, and has a shed roof. A dry room for laborers abuts the southwest end corner of this wing.

Throughout the interior of both wings, the walls and ceilings are open, exposing the trusses and timber framing, except for the rod mill section which has metal framing. The floors in the lower level of the building are concrete, while wood and metal grate catwalks provide access to higher levels. The original milling machinery remains virtually intact as do the machines added during the course of the mill's operation. Most of the original machinery was used throughout the entire productive life of the plant and remains functional, although some devices are no longer connected to the process flow. Flotation cells were replaced as they wore out, but replacements generally occupy the footprint of their predecessors. Some pieces of equipment were removed over the years, including the wet bucket elevator and the unusual Fagergen concrete flotation cells. In addition to the destroyed tramway towers, a section of the tram rail that carried buckets over the original dump station was cut out when the crushing plant was built. The cam-like camel that automatically clamped the buckets onto the traction cable remains in place, but the corresponding camel that disconnected them is missing.

One aspect of Shenandoah-Dives Mill that remains mysterious is the 1930s-era sampling plant. No drawing or photographs of it have been located, except for a couple of general site photographs that show a different building where the crushing plant now sits.

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[4] "Bureau of Mines Report, State of Colorado, for the years 1929-1930," and Allen Nossaman, "Building

Although descriptions imply that it contained crushing equipment, no specifications for crushers or conveyors, physical evidence of their presence, or disposition records have been located. It is possible, of course, that the sampling plant was only that, an assay laboratory to evaluate custom ores, but if that was the case, it is not evident how the bulk of these ores were crushed prior to their conveyance to the fine ore bin.

ASSOCIATED BUILDINGS AND RESOURCES AT MILL SITE

The site includes several ancillary buildings and structures, which were beyond the scope of this project although they were directly associated with the mill's operation. Various detritus, including defunct machinery, can be found around the mill site as well.

Office/Assay Building

The Shenandoah-Dives Mill office/assay building (see also HAER No. CO-91-A) is a rectangular, three-story frame building with a slightly gabled roof. The original windows are two-over-two double-hung while replacement windows are stationary single light. Completed in summer 1929, the three-story building measures approximately 30'x40'. According to inspector reports, the building as constructed had "Insulex walls and ceilings" with exterior walls of Oregon fir timber shiplap siding.

The lowest story is below grade and built into the side of the mountain. This level contains a kitchen and bathroom in addition to two other rooms. Stairs at the southwest and northeast corners access the ground level. Doors open to the balcony that runs along the east and south facades.

The ground level has two entrances on the west façade as well as a set of stairs on the exterior leading to the upper level. This level has five rooms whose uses are not known, what appears to be a lab in the center, and a bathroom. A concrete vault is located in the northeast corner. A stairway in the northwest corner provides interior access to the upper level.

Inventory Record" for the Mayflower Mill, 1995, Colorado Historical Society.

The upper level has a concrete vault in the northeast corner as well. This level also contains a kitchen, bathroom and four other rooms whose use is not known. There is a covered balcony on the south façade.

Water Storage Tank

The 27’x20’ (height by diameter) circular water storage tank was built in 1929 at the northwest end of the main mill building, in the vicinity of the rod mill section of the east-west wing of the building. Several steel pipes run from the tank into the rod mill. The tank was constructed of wooden staves with enormous steel rings to hold the staves in a cylindrical shape. The conical roof was fashioned with timber supports and sheeting and covered with asphalt shingles applied in a circular pattern. Although this is the only water tank currently in this area, a 1929 mining report and photographic evidence indicate that originally there were two such tanks. The second, located where the rod mill is today, was demolished when that addition was constructed.

Coal Storage Tank

The circular coal storage tank, adjacent to the southeastern end of the north-south wing of the main mill building, was constructed in 1929. It is built of wooden staves and steel rings with a conical roof fashioned from timber supports and sheeting covered with asphalt shingles, making it very similar in design and construction to the water tank. A timber trestle supports a wooden ramp from a gravel drive at the upper level of the mill to the top of the tank. Trucks backed along the ramp to unload coal into the tank through a chute at the pinnacle of the roof. Next to this ramp is a support structure for transformers that furnish electrical power to the mill.

Guard Shack

A rectangular, frame structure with a gabled, corrugated metal roof was built at the entrance to the fenced mill facilities in 1982. Its main entrance is in the east wall, which has two glazed doors, reached via wooden steps, and a one-over-one light window.

The north elevation contains one stationary window and a glazed door. The west elevation features a side-by-side window and glazed door.

Dry Room

The Dry Room is a prefabricated rectangular building with a gabled corrugated-metal roof. It was installed in 1986 to serve as a shower room for mill employees. A wooden porch was added at the centrally located entry. Two doors in the south wall provide access into the building.

Valve House

This small, rectangular building clad in corrugated metal siding is located across the entrance road from the guard shack. It was built to house and provide freeze protection for the main valve to the mill's water system.

Lime Storage Building

This rectangular 50'x40' building is clad in corrugated metal. A garage-type door is located on the east elevation, with an entry door for personnel next to it. Sunnyside Gold Company had the building erected in 1986.

Treated Water Tank

Located just east of the Lime Storage Building is a cylindrical steel tank used to store treated process water. The precise construction date is unknown, but it likely was built about the same time as the Lime Storage Building, 1986.

Tailing Ponds

Four ponds were ultimately built within a triangular-shaped portion of land southwest of the mill site. The two oldest ponds, numbers 1 and 2, were in use from the 1930s through the 1960s, while numbers 3 and 4 served as the tailings repositories after being opened in the 1970s. During the 1990s pond number 4 received tailings from the abandoned Sunnyside Mill in Eureka as part of wider reclamation activities in San Juan County.[5]

CHAPTER 3: MINING IN THE SAN JUAN MOUNTAINS OF COLORADO

Mining in the region began as early as 1765 when the Spaniard Juan Maria Antonio Rivera and his men entered the San Juan Mountains of Southwest Colorado searching for minerals. Rivera's excursions were the beginning of many that prompted westward expansion across the United States and development of the mineral and mining industry in the Rocky Mountains.

Gold and silver rushes drew hundreds of thousands of gold-rushers to prospect the San Juan Mountains, home of the nomadic Ute tribe. In the 1860s trappers and miners ventured into the mountains in search of hides and metals. Capt. Charles Baker, financed by S. B. Kellog, led the first mining party into a small park in the San Juans. They returned a year later to placer mine, but the Civil War interrupted these initial mining efforts. They did not return until 1870.

Although miners were initially interested in gold, they discovered more silver than gold, and non-precious metals such as lead, zinc, and copper (also called base metals) were found in proximity to the gold and silver veins. The ores of the San Juan Mountains are complex sulfide ore bodies that contain several metals chemically bound to sulfur oxides. Eventually twentieth-century technological advancements and investment in the hard-rock-mining industry replaced gold fever and strengthened the base metals market, but in 1871, precious metals were the draw. That year a potentially profitable silver vein was located in Arrastra Gulch, just east of what is now the town of Silverton, Colorado. The Little Giant Mine was the first significant site in the area for lode mining.[6]

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[5] William R. Jones, "History of Mining and Milling Practices and Production in San Juan County, Colorado, 1871-1991," in *Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado*, U.S. Geological Survey Professional Paper 1651 (Denver, CO: U.S. Geological Survey, in press).

[6] A lode is defined as an expansive, underground ore body. Though often used interchangeably with the word vein, a lode consists of several mineral veins spaced closely enough together to be mined as a unit. Miners reach and follow a lode or vein via underground tunnels to extract ore containing the desired minerals.

A record number of mining claim notices, or patents, were soon filed, but they were declared illegal because the federal government recognized the mountainous region as Ute Territory. Conflict arose between the groups as more Euro-Americans moved into the region looking for gold and silver. Miners led by Frederick Pitkin (later the first governor of Colorado) lobbied the federal government for control of the region, and their efforts ultimately resulted in the Brunot Treaty in September 1873.

During 1871 and 1872, while the treaty was being negotiated between Felix Brunot, chairman of the Board of Indian Commissioners, and Chief Ouray, the Ute representative, nearly 1,500 claims were recorded. After the agreement was signed, the federal government opened the San Juan Mountain region. The seven bands of the Ute tribe were removed to New Mexico, western Colorado, and eastern Utah.[7] Previous patent owners quickly re-filed their location notices in county and state offices.

As miners and laborers moved into the newly opened mining district, towns such as Howardsville, Eureka, Animas Forks, and Silverton sprang up virtually overnight. Silverton, Colorado, established in September 1874 and incorporated two years later, is located in the center of the San Juan Mining District.[8] Although Howardsville was the county's first seat, Silverton quickly wrested the honor in 1876. One of the oldest mines on record in San Juan County is the Sunnyside Mine discovered in 1873, while the area was still under the control of the Ute tribe. Its owners re-filed their original location notices on August 18, 1874.[9] At that time, mules following treacherous mountain trails and aerial tramways moved ore from mountain mines to the valleys below. In 1879 Otto Mears, a road builder in the San Juan region, opened the first toll road (the Stony Pass Wagon Road between Silverton and Del Norte) to provide better access to the outside world, although the route over 12,590' Stony Pass was difficult.

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[7] Dawn Bunyak, "Silverton Historic District (HD), National Historic Landmark (NHL)," No. 66000255. U.S. Department of the Interior, National Park Service, National Historic Landmark Office, October 15, 1966 (hereafter cited as Silverton HD NHL, 1966); Peter Decker, *The Utes Must Go* (Golden, Colorado: Fulcrum Publishing, 2004); and Virginia Simmons, *The Ute Indians of Utah, Colorado and New Mexico* (Boulder, Colorado: University Press of Colorado, 2000).
[8] Silverton is the only incorporated town in San Juan County.
[9] Allan G. Bird, "A Report on the Mineral Properties of Standard Metals Corporation, Nov. 10, 1979," prepared for First Mississippi Corporation, located in Russell L. and Lyn Wood Mining History Archives, Colorado School of Mines, Golden, Colorado.

The first railroad, the Denver and Rio Grande Railroad, began service between Silverton and Denver in July 1882. Three other lines soon followed to connect the surrounding area to the Rio Grande at Silverton: the Silverton Railroad (1889), the Silverton Northern Railroad (1895), and the Silverton, Gladstone & Northerly Railroad (1899), with all but the last built by Otto Mears.[10] Because of the rugged nature of the San Juan Mountains, these were all three-foot, narrow-gauge lines. With smaller equipment and sharper allowable curves than standard-gauge railroads, narrow-gauge lines were much cheaper to build in mountainous areas. Trains provided economical transport of ore from the San Juan County mines to the smelters, and production increased as reduced transportation costs for ore stimulated development.[11] The district flourished, producing more than $65 million in precious ores between 1882 and 1918.[12] The population of Silverton peaked at a little more than 2,000 in 1910.[13]

Mining historian William Jones declared, "…mining development greatly expanded due to Federal Government [*sic*] supports, stable to rising commodity prices, and improved technologies [between 1890 and 1913]."[14] Mining engineer T. A. Rickard credited ball-mill grinding and froth flotation as ore-concentration technologies that revolutionized twentieth-century mining.[15] In 1917, the United States Smelting and Refining Company built a new mill named Sunnyside, in the town of Eureka.[16] The men at the Sunnyside Mill are credited with perfecting the flotation of two minerals (lead and zinc) from a complex ore. By the 1920s, the fundamentals of froth flotation had been established and put into worldwide use.

After World War I, mining in the Rocky Mountain West suffered a severe decline due to a drop in demand for metals. The San Juan region languished until the "Million

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[10] Silverton HD NHL, 1966.
[11] William R. Jones, "History of Mining and Milling Practices & Production in San Juan County, Colorado, 1871-1991," *Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado,* (Denver, Colorado: U. S. Geological Survey Professional Paper 1651, In press).
[12] Silverton HD NHL, 1966.
[13] Colorado State Demography Office, "Historical Census Population for years 1880 to 2000," accessed from http://dola.colorado.gov/demog, September 2005.
[14] Jones, "History of Mining and Milling Practices."
[15] Jones, "History of Mining and Milling Practices."
[16] This Sunnyside Mill in Eureka is not to be confused with the 1980s-era use of the Sunnyside Mill name for the mill near Silverton that is the subject of this report.

Dollar Highway" or U. S. Highway 550, built primarily on the roadbed of the recently abandoned Silverton Railroad, opened in July 1924. The following year, Charles A. Chase arrived in Silverton to conduct a geological survey for a Missouri syndicate. Chase believed the area could still be profitable, and within a short time the Shenandoah-Dives Mining Company opened east of town. It quickly became the major employer in the district. With improved transportation routes into the region, the minerals business was again viable, and the market remained relatively constant for several years.

The mining industry experienced one of its darkest and longest economic depressions after the 1929 stock market crash. During the Great Depression, many mines and associated communities in the San Juan region failed and closed. Several mills and the Durango smelter were mothballed. Miners wandered the district looking for work. However, through economy and working with local businesses, the Shenandoah-Dives Mining Company was able to stay in operation.

After the abandonment of the gold standard and the Silver Purchase Act of 1934, which authorized President Franklin D. Roosevelt to buy silver until the price reached $1.2929 an ounce or until the value of the amount held by the government reached a third of the value of the amount held of gold, the western mining regions experienced a moderate boom period. At the same time, much of the world began to re-arm in fear of another world war, and the industry benefited from an increase in demand for most metals. Accordingly, mining activity in the San Juan region resumed. As American economic activity focused upon military preparedness, the federal government classified mining and milling operations as either essential or non-essential to national security, and it suspended all non-essential operations—those that counted more than 30 percent of their dollar value in gold and silver—in 1942, including Silverton's Shenandoah-Dives Mining Company. The War Department granted the company special permission to continue operations because of its substantial base-metal production, and its mill was one of the first plants to resume activity in the U. S. mining and milling community.

World War II ushered in a period of artificially inflated prices for America's natural resources that revived the mining industry. During the conflict, the federal government guaranteed defense contractors funds to cover the costs of converting and expanding their plants for defense production, along with a hefty operating profit, but the industry experienced a bust cycle at war's end when these federal subsidies ended. Once again, the base-metal industry languished under high labor costs and diminishing markets.

U. S. metal prices continued to drop during the 1950s due to the availability of cheaper foreign metals, which flooded the market when the Paley Commission, appointed by President Dwight D. Eisenhower, encouraged Americans to purchase foreign metals to help abate communist activity in smaller countries. Consequently, the domestic metals market collapsed, and the future of the Shenandoah-Dives operation in Silverton looked bleak. General Manager Charles A. Chase organized a campaign to fight for its survival, but despite a valiant effort, Chase fell short, and the mining operation closed in 1953. With the closure of Shenandoah-Dives, miners left the area in search of employment. The closing severely impacted the economy of the entire region, as small mines who relied upon the large company for its milling needs also failed. Between 1950 and 1960, Silverton lost approximately 40 percent of its population.[17]

Over the next three decades mining operations in the Silverton area were generally small in nature. The Shenandoah-Dives mine and mill intermittently re-opened under new ownership until the Standard Metals Corporation eventually bought the operation in 1960. Rising gold and silver prices in the late 1970s prompted yet another increase in mineral exploration in San Juan County, but prices did not maintain a high level long enough to sustain any large-scale mine development. At the same time, new surface reclamation laws began to affect mining operations. Legislative policies related to complex environmental regulations in the 1980s prompted all major American and Canadian mining companies exploring in San Juan County to terminate leases and exploration.[18] Despite Standard Metals' efforts to upgrade the flotation mill by installing an on-site crushing plant, it was forced to sell in 1985 after a series of unfortunate accidents, bankruptcies, and elevated costs.

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[17] The 1950 census recorded a population of 1,375 in town and 1,471 in the county. By 1960, it had fallen to 822 in town and 849 in the county.
[18] Jones, "History of Mining and Milling Practices."

The Canadian firm Echo Bay Mines Limited re-opened the mine and mill as the Sunnyside Gold Corporation in 1985. After only six years of production, the company permanently closed the mill—by then known as the Mayflower Mill—and plugged its mine. After 1991, mining and exploration in the county, state, and most other western districts ceased because of low metal prices and increased expenses related to new economic and political policies.[19]

The former Shenandoah-Dives Mining Company was the last large-scale mining operation in San Juan County. After 121 years of mining in San Juan County, the mines, mills, and roads fell quiet.

Like so many western boom towns, Silverton might well have turned into a ghost town, but its history—and a few people who realized just how important that history was—saved it. Fortunately, Sunnyside Gold did not think it particularly worthwhile to remove the equipment and demolish the Mayflower Mill right away, and a small group of dedicated individuals with the San Juan County Historical Society convinced the company to donate the mill to them so that it could serve as an interpretive museum. Thanks to their efforts, an important piece of technological and cultural history survives, and both Silverton and San Juan County survive with an economy based largely upon mining-history tourism.

CHAPTER 4: THE SHENANDOAH-DIVES MINING COMPANY

In the summer of 1925, a group of capitalists from Kansas City, Missouri—later known as the Shenandoah-Dives Syndicate—contracted with mining engineer Charles A. Chase of Denver for preliminary mining exploration and development in the San Juan Mountains of southwestern Colorado.[20]

Chase was already familiar with the region and its resources. He had first visited the San Juan Mountains in 1899 at the invitation of Arthur Winslow, owner and manager of the Liberty Bell Mine in Telluride, Colorado. Working himself up from company

[19] Jones, "History of Mining and Milling Practices."

surveyor and assayer, Chase eventually became general manager of the Liberty Bell Gold Mine and continued to work there for twenty-five years until it closed in the 1920s.

Chase's subsequent proposal to James Oldham and Clifford Histed of the syndicate was to purchase and consolidate the Shenandoah-Dives, North Star, Terrible, and old Mayflower mines into one large mine twice the size of the old Liberty Bell. Acting on Chase's recommendation, the Kansas City group raised capital to purchase thirty-one patented and twelve unpatented claims covering 316 acres. Between 1925 and 1927, the syndicate began developing their Colorado holdings, with Chase serving as general manager of the Shenandoah-Dives mining operation.

In the development stage of the mine holdings, Chase hired twenty-seven men as machine operators, trammers, cagers and top men. They were supported by blacksmiths, carpenters, cooks, firemen, and related helpers. An engineer oversaw the entire crew's work. At the same time, Chase hired James McKay as foreman in the mine. Soon after, the men opened a new tunnel at the old Mayflower Mine, and early production garnered approximately $400,000 in mineral wealth.

By July 1928, the nascent company was also profiting from the use of the Iowa Tiger Mill, a rented mill located in Arrastra Gulch well below the mineshaft. The men modified a small aerial tramway to run from the Mayflower Mine to the Iowa Tiger Mill to carry ore from the mine to the mill for processing. This would be a temporary measure until the company built a new tramway and mill (best known as the Shenandoah-Dives Mill). Over the life of the mill, each owner referred to the mill differently, so at various times it was known as the Shenandoah-Dives Mill, Standard Metals Mill, Echo Bay Mill, Mayflower Mill, and Sunnyside Gold Mill. This can be confusing, but its first and longest operation was as the Shenandoah-Dives Mill, so that will be the name generally used in this report.

Later that year, Chase presented another prospectus to the syndicate outlining proposals for a tunnel, tramway, and mill. The principle needs were mine equipment and crushers at the mine; a mine house and offices; a cable tramway; a mill and adjacent

[20] For more history on Charles Chase and the Shenandoah-Dives Mining Company, refer to Dawn Bunyak, "The Shenandoah-Dives Mining Company: A Twentieth-Century Boom and Bust," *Colorado Heritage* (Spring 2003), 35-45. This section was drawn from this work unless otherwise noted.

structures; and a working fund of $50,000. The syndicate accepted Chase's prospectus in June and transferred funds to the company.

Chase began construction of the mine and mill immediately. He turned to his colleagues in Denver for assistance with the design and construction of the flotation mill he planned to build at the base of the mountain. He hired a former colleague from the Colorado School of Mines, Arthur J. Weinig, as consulting metallurgist and engineer to design the metallurgical process. Denver-based Stearns-Roger Engineering Company designed the structure in consultation with Weinig. Chase also hired Thatcher R. Hunt to be the mill superintendent, but retained for himself overall charge of the site and general layout of the mill.

Crucial to the success of any mining operation is a large labor pool. Men traveled into Silverton from all over Colorado and the West to see if they could get a job in the mine. To provide housing for its laborers and miners, the Shenandoah-Dives Mining Company built a boarding house near the Mayflower Mine portal. The boarding house was home for single and married men whose families did not live in Silverton.

In addition to the boarding house, buildings at the Mayflower Mine included the initial tramway terminal building (later expanded to become the Shenandoah-Dives terminal) and a 300', auxiliary tramway with terminal to the boardinghouse. The mine's underground facilities included a crushing plant, compressed-air plant, blacksmith shop, and foremen's office. These were built underground for protection against the substantial snowfall and frequent avalanches in the San Juan Mountains. A short underground passage connected the mine and the boarding house so that miners could walk to and from work despite the weather conditions. Miners walked from the boarding house past the first-aid room into the dry room, and then into the main level of the mine.

For mines not accessible by vehicular traffic, aerial tramways were the lifeblood of the operation. Due to the high-altitude location of the mines and treacherous mountain trails, early Silverton mining operations relied upon mules and aerial tramways for transportation of ore and men to and from the mine. Later vehicular trails clung to the precipitous slopes of the mountain but still ended well below mine portals. A main aerial tramway connected the Mayflower Mine to the Shenandoah-Dives Mill, and a 300' auxiliary tramway connected to the upper terminal delivered loads of freight from the main tramway to the mine and hotel.

With only a steep trail to the mine, the tramway carried men and mine equipment as well as ore. Married miners living in Silverton boarded the tramway at the mill to travel to and from their jobs at the mine. Retired miners recall that winds set the buckets swaying to and fro, but they never feared for their lives. While only men worked in the mines at that time, miners' wives visiting the commissary or women working at the boarding house bundled their skirts around their legs and rode the line to the top as well.

In June 1929, the Kansas City Syndicate incorporated in Colorado as the Shenandoah-Dives Mining Company with James W. Oldham as president. The company's general offices were located in Kansas City, Missouri, with mine operations near Silverton. Colorado approved issuance of 3,500,000 shares of common stock at $1 par value. Chase continued to develop the mine while the investors pursued incorporation.

At that time, Shenandoah-Dives was the largest single, industrial payroll in the "Four Corners" area (the adjoining portions of Colorado, Utah, New Mexico, and Arizona). By 1930, the company had invested $1,250,000 in its Silverton operations, and between 1930 and 1932, the mill processed 461,826 tons of ore. The Great Depression forced industries nationwide to close, including many mines and mills, but Charles Chase's cost-efficient management kept the Shenandoah-Dives operation viable. Base metals were the economic basis of this viability. During the 1930s, the company's production of lead, zinc, and later copper-zinc helped meet some basic needs of America's manufacturing companies as the country struggled to recover from the depression. Meanwhile, other mining regions dependent upon gold output languished, experiencing intermittent openings and closures as the price of gold went up and down.

With the abandonment of the gold standard in 1934, the Silver Purchase Act, and the rise in gold prices from $20.67 to $35 per ounce, the mining regions of the West experienced a moderate boom period that ended the mining industry's depression. Dormant mines now stirred to life. By the end of 1934, the State of Colorado ranked third for recovered gold and fifth in silver production.

In 1938, 262 men worked for the Shenandoah-Dives Mining Company in Silverton. Miners, timbermen, trammers and loaders, trackmen, and motormen were paid $4.95 daily. Although the Shenandoah-Dives operation paid wages comparable to industry standards, its miners and laborers went on strike in mid-year over disagreements about wage rates and the length of the workday.

Organized labor and labor actions were not new to Shenandoah-Dives; in fact, they went back over forty years. In 1894, during a major period of unionism, the miners of Silverton formed the Silverton Miners' Union, Local Number 26 of the Western Federation of Mine, Mill and Smelter Workers. Economic dislocations between 1890 and 1900 prompted formation of monopolies. This new era of corporate organization led to the growth of labor organizations. Local Number 26's peak membership years were between 1894 and the late 1920s. Nevertheless, unionization remained strong into the 1930s and 1940s in Silverton.

Unionization had improved the miners' working conditions, hours, and wages. Congressional passage of the 1938 Hours-Wages Law (Fair Labor Standards Act), which established the forty-hour work week, set the minimum wage rate, and abolished child labor, added strength to the union's battle for better working conditions. Although Chase attempted to meet most of the needs of his employees, pressures from the board of directors forced him into the awkward and uncomfortable position of balancing the desires of absentee owners with those needs.

In 1938, the Shenandoah-Dives Mining Company lowered the base wage rate to counter the effects of the Hours-Wages Law. In addition, new company rules required an eight-hour workday and overturned earlier agreements between union and company officials for a "portal-to-portal" workday of six hours. Unconsulted and angry, the miners of Silverton Miners' Union, Local Number 26, reacted by going on strike in July 1938.

After several weeks of unsatisfactory negotiations between the company, union negotiator A. S. Embree and local union officers, union members decided to take matters into their own hands. The financial collapse of companies during the Great Depression had forced the closure of many local and regional mining operations. With this in mind, miners were anxious to resume operation before the company closed Shenandoah-Dives as well.

Members of Local Number 26 disbanded their organization to create a new local representing their current concerns. In late August, they became the San Juan Federation of Mines, Mills, and Smelter Workers, a separate organization from the Western Federation of Mines, Mill, and Smelter Workers. The defunct Local Number 26 turned over remaining assets to the new union, resumed negotiations, and the miners went back to work on the seventh of September.

Having done all he could to secure the best possible arrangement for the miners given his board's mandates, the paternalistic Chase took the strike personally. In his March 1939 Report of Operations, Chase reported that the local union "attack" in the autumn of 1938 culminated in a strike that "impaired the cash position" of the company seven months after the strike.

The negotiated agreement included a new work-versus-pay policy. Chase implemented a contract mining system whereby more productive workers earned more. This, in turn, lowered company costs and allowed the mine and mill to remain open. Since such a compensation system was not possible for non-production workers, their pay remained at set rates. Rates included a daily wage of $4.40 for hoistmen and freight handlers, while bucketmen earned $4.70 per day for a seven-day week. Waiters received $80 a month, but cooks earned $165 per month. Clearly, food had a high priority!

To insure the success of the Shenandoah-Dives operation, Chase built and ran the Silverton complex with the newest, most-efficient mining and milling processes available. In 1942, the journal *Mining World* featured the Shenandoah-Dives Mine, stating:

> Based upon a thorough exploration and determination of the ore reserves, General Manager Chase, with his staff of engineers, has built the physical properties of the Shenandoah-Dives Mining Company for the long-time operation, and they are proud of the fact that this planning has resulted in few changes in methods of operation due to later developments. It has only been through the courage and foresight of Mr. Chase and his associates that mining has been kept alive in the Silverton District.[21]

[21] "Shenandoah-Dives. Part Two," *Mining World* (June 1942), 13.

Though Chase's management skill was appropriately praised, the journal unfortunately neglected to mention the over-two-hundred miners and laborers who worked the mines, even though Chase's plans would have come to naught without their diligent, hard work and commitment to the operation's success.

Inside the Shenandoah-Dives Mill, metallurgist Weinig designed the metallurgical operation for the fullest recovery of metals, using alcohol reagents to separate three products from the ore. Further process-development work and equipment upgrades enabled the mill to eventually separate five products: gold, silver, copper, lead, and zinc.

The Shenandoah-Dives Mill operation also reflected the increased environmental concerns of the mining and milling industry of the early twentieth century. Since its territorial days, Colorado had maintained legislation outlawing stream pollution, but mining companies often ignored these laws. At the turn of the century, mining activities focused on recovering metals in the quickest and most cost-efficient manner possible, but money spent on environmental controls only increased costs. Since society generally accepted that mining was a vital ingredient of the industrialization, modernization, and progress of the United States, its deleterious effects were often overlooked.

However, this situation changed somewhat after 1884, when California's Yuba and Feather Valley farmers successfully sought retribution from hydraulic miners for the extensive environmental damage their operations had caused. This case set a precedent for future lawsuits by the agricultural community against the entire mining industry. The California case prompted some members of the mining community to devise innovative processes conducive to environmental care. Where prior mining practices had denuded timber growth, polluted water sources with tailings, and poured noxious gases into the air, Chase and a small number of other mine operators sought to install cleaner, environmentally safer methods to help protect the locales in which they worked and lived.

The Shenandoah-Dives operation was the first in the San Juan region to utilize tailing ponds. At the time, common practice was to slurry the tailings into available waterways, despite the dangers to the water supply and aquatic population. Chase consulted with J. T. Shimmin, who had devised a method of creating "ponds" of tailings, at mills in Butte, Montana. Shimmin had built earthen dams to contain ponds of mostly liquid slurry until the water could be extracted to leave the solid tailings.

After a trip to Montana, Chase returned and altered Shimmin's design to fit a triangularly shaped piece of land adjacent to the Shenandoah-Dives Mill. In light of the soil content of the substructure, Chase had the mill's tailings, which were in slurry form, deposited on the south side of the mill. As each pond was created, water was decanted off the surface, filtered, and returned to the mill for reuse. Most of the remaining water evaporated or percolated through the tailings and into the substructure, eventually leaving essentially dry ore, but without most of its metal content. The location of the pond minimized percolation into the Animas River. After a trial period with a few mishaps due to freeze and thaw, the tailing ponds of the Shenandoah-Dives Mill took shape in 1935. Additional ponds were established as the original ones neared capacity. Even with design changes introduced during the trials, the ponds failed twice (in 1947 and 1974) after extreme temperature swings and freeze-thaw cycles opened gaps in their containment structures that allowed discharges into the river. These were promptly repaired and the surrounding area cleaned up.[22]

World War II ushered in a period of artificially inflated prices for essential resources and revived the mining industry across the nation, including the Shenandoah-Dives operations. The advent of World War II also brought other changes to Colorado as military installations and scientific developments were established in the state.

As economic activity focused almost exclusively on military needs, the federal government classified mining and milling operations as either essential or non-essential. In 1942, the government declared all mines with more than 30 percent of their dollar value in gold and silver to be non-essential and suspended their operations. Although the Shenandoah-Dives Mine and Mill's gold and silver production was only a by-product of its base-metal ore production, it nevertheless exceeded the limit, and the federal government shut the operation down.

[22] Jones, "History of Mining and Milling Practices."

A letter-writing campaign by Chase, *Mining World*, and Colorado State legislators to the War Department ensued. Their appeals were heard, and they convinced the government that Shenandoah-Dives' base-metal production was essential to national security. The War Department reconsidered its decision and granted the Shenandoah-Dives Mill permission to continue operations. The Shenandoah-Dives' selective-flotation mill was one of the first plants to resume activity. Chase and his men returned to work to supply America's needs throughout World War II and the Korean War.

Nevertheless, ore production declined as demands for American metals diminished. Rising costs under a fixed selling price that capped growth plagued the industry. When the wars ended, the demand for metals quickly dried up. Stockpiled metals met the needs of manufacturers, who turned from munitions production to consumer products. Other industries flourished, but the gold and base metal industry languished.

During President Truman's administration, the Shenandoah-Dives Mining Company received a government grant for exploration of new veins, but lower grade ores and rising labor costs made any new venture unprofitable. Foreign metals flooded the United States market after the Paley Commission, appointed by President Eisenhower, encouraged businesses in the United States to purchase foreign metal in hopes of abating communist activity in smaller countries. As a result, metal prices collapsed, along with the future of the Shenandoah-Dives operations in Silverton.

As company officials debated the closure of the Shenandoah-Dives' mines, Chase again fought for its survival. He organized another letter writing campaign to the Shenandoah-Dives Mining Company's board of directors, Colorado congressmen, and banks. In letters touting the productivity of the plant and relating the artificial market of late, Chase sought money for exploration that might keep the operation alive. The new investors and stockholders did not have the same emotional ties to the operation that Chase did, and with little likelihood of quick profits, they chose to abandon the operation.

In 1953, after twenty-five years of mining and milling in Silverton, the Shenandoah-Dives Mining Company shut down its operations. During the previous twenty-four years, the mill had processed 4 million tons of Shenandoah-Dives Mining

Company ore and 186,000 tons of "custom ore" from surrounding smaller enterprises, shipping the milled products to various smelters. In total, the Shenandoah-Dives Mill had processed 11 percent of all the gold, silver, copper, lead, and zinc in Colorado. At the time, the assayed value of the Shenandoah-Dives Mill production of concentrates shipped to the smelter was $32 million.

Mismanagement, low ore reserves, poor mining methods, and misrepresentation spelled the end for many mining companies in the 1950s, but that was not the case for Shenandoah-Dives. Chase's resourceful management had kept the company afloat through several tough periods, and it had continued to invest in improved technology for its mines and mill. In the end, even these attributes were not enough to overcome all the market forces stacked against it.

With the company's demise, smaller, local companies lost their primary milling resource and were also forced out of business because of the prohibitive cost of ore transportation to distant mills. At its closure, the mill was processing 94 percent of all ore mined in San Juan County. The town of Silverton, with a population of 1,375 in 1950, lost 40 percent of its residents over the next ten years due to the closure of local mines.[23]

The syndicate fired Chase as general manager and then retained a caretaker for the property. Chase moved to Denver, where he unsuccessfully sought investors interested in the Shenandoah-Dives Mining Company. The frontier regions had long looked to the East for investment capital, but the seemingly endless pool of funds had finally run dry. After a lengthy illness, Charles Chase died in Denver on August 31, 1955.

Although the syndicate had fired Chase and closed down the Shenandoah-Dives Mining Company in 1953, these actions did not signify the permanent demise of its operations. Between 1953 and 1957, the mill operated intermittently while the company underwent a series of management changes. Under a Defense Minerals Exploration Act (DMEA) grant, Shenandoah-Dives actually continued limited ore exploration in a Silver Lake lease. This was, however, unsuccessful, and Shenandoah-Dives again tried to sell the mine and mill.

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[23] Colorado State Demography Office, "Historical Census Population."

The Shenandoah-Dives Mining Company never managed to sell the property outright, but instead merged with Marcy Exploration Corporation, a uranium mining company located in Durango, Colorado, thus creating the Marcy-Shenandoah Corporation in 1957. With continued low demand for metals, however, the mine and mill remained closed. Another opportunity did arise that fall, when the mill became the setting for an unusual, new endeavor. Universal Studios filmed portions of the movie *Night Passage*, with Jimmy Stewart and Audi Murphy, at the mill, using the tramway in one memorable sequence. While this proved to be profitable—certainly more so than metals production—it turned out to be a one-time occurrence. Hollywood had no further demand for such a set.

After unsuccessful efforts to obtain additional mine leases, including the Sunnyside Mine, Marcy-Shenandoah Corporation sold an "undivided one-half interest" in the Shenandoah-Dives mine and mill to the Standard Uranium Corporation of Moab, Utah, only two years later. A limited partnership, Shenandoah Limited, developed mining properties and began to drive a tunnel under the Sunnyside Mine using the old Gold King Tunnel at Gladstone.[24]

In 1960, Standard Uranium Corporation changed its name to Standard Metals Corporation and Marcy-Shenandoah accepted a buy-out offer from Standard Metals. The mill subsequently processed ore from the Silver Lake and Shenandoah-Dives mines. Both mines closed in January 1961 due to declining base metal prices, but the new American Tunnel into the Sunnyside Mine was successfully opened. Actually the American Tunnel was the combination of a 1-mile-long tunnel drilled in 1905 for the Gold King Mine and new work by Standard Metals that enlarged the existing tunnel and extended it another mile to reach the Sunnyside Mine.[25] This ore body, as well as custom ore, was processed at the Shenandoah-Dives Mill.

[24] William Jones, "Chronological Outline of Shenandoah-Dives (Mayflower) Mill," April 21, 1996. Jones compiled the outline from Shenandoah-Dives Mining Company promotional reports (1926-1928) and annual reports (1931-1952); Standard Uranium and Standard Metals annual reports (1959-1968); mine inspectors' reports (1929-1938, 1960-1977); and Silverton National Historic Landmark District Boundary Increase nomination by Dawn Bunyak for the National Park Service.

[25] Bird, "A Report on the Mineral Properties of Standard Metals Corporation, November 10, 1979."

The continued decline in metal prices, unwarranted acquisitions, and poor investments caused the Standard Metals Company to file for bankruptcy in 1971. A series of accidents in the 1970s (failure of the tailing pond in 1974 and the intrusion of Lake Emma into the Sunnyside Mine in 1978) seriously impacted the financial stability of the company, but it nevertheless managed to operate in receivership until April 1985.[26]

Standard Metals sold its mothballed Shenandoah-Dives holdings to the Sunnyside Gold Corporation, a subsidiary of the Echo Bay Mining Company of Edmonton, Canada, in November 1985. Sunnyside, who adopted the Mayflower name for the entire operation, and associated companies participated in two joint ventures utilizing the mine and mill. By 1990, however, Sunnyside Gold was the sole owner. It shut the mill down again a year later. With a continuing decline in the price of zinc and a lack of gold reserves, Sunnyside Gold announced the permanent closure of the Mayflower mine and mill in 1992. By 1996, the federally required surface reclamation of the tailing ponds and mine site had been substantially completed.

Sunnyside Gold donated the flotation mill and affiliated lands to the San Juan County Historical Society. Through the hard work of local preservationists and the San Juan County Historical Society, the Shenandoah-Dives (Mayflower) Mill reopened as a museum in 1997. In February 2000, Secretary of the Interior Bruce Babbitt designated the mill as a National Historic Landmark representing our nation's mining heritage.

CHAPTER 5: THE DEVELOPMENT OF FLOTATION MILLING

Prominent mining historians have recognized the development of flotation and selective flotation as the beginning of modern mining. The efficient treatment of ore, specifically hard-rock ore, was crucial to the history of American mining. The Sunnyside Mill in Eureka developed the first selective flotation circuit to produce a lead-zinc product. Almost a decade later, a more-modern concentration plant, the Shenandoah-Dives Mill, opened nearby in Silverton to process copper, lead, zinc, silver, and gold.

After ore is extracted from the earth, ore processing begins with the mechanical separation and collection of valuable metals. The first step is crushing the ore into a sand

[26] "Sunnyside Mine, Part 1, San Juan County, Colorado," Standard Metals Corporation Annual Report

or powder in the reduction stage. The second is concentration, where the crushed ore is mechanically or chemically treated to extract valued metals. Concentration increases the value of ore by recovering the most valuable minerals in the highest grade possible or the purest form of concentrate. In order to effectively treat the ore, three factors must be considered: 1) the major minerals present, 2) the relative abundance of minerals, and 3) the grain size of various minerals.[27] With these factors in mind, the metallurgist chooses the concentration process that will obtain the highest yield from each type of ore. For purposes of this report, minerals and metals generally will be referred to as metals, since the Shenandoah-Dives Mill primarily concentrated hard-rock or complex ore bodies for industrial metals, such as copper, lead, and zinc.

Ore Processing

In the majority of mills, the ore concentration process to recover valuable metals is divided into four distinct areas: crushing, grinding, concentration, and drying. Comminution is the crushing or pulverization of ore into minute particles by mechanical means. This finely ground material allows enhanced recovery of desired metals using several methods, including selective flotation. Crushing can be accomplished through a variety of machines.

Mechanical crushing technology began with the arrastra, a simple apparatus having a rock floor or base and a heavy stone on a central pivot powered by water or an animal. Ore dumped onto the floor was pulverized as the heavy stone passed over it. Later in the nineteenth century, other mechanical crushers, such as stamp mills, jaw crushers, and gyratory crushers, were developed.

Stamp mills worked like a hammer. Large weights attached to wooden or metal arms connected to a camshaft were dropped from their highest point onto ore deposited into a trough, often made of concrete, pounding the ore until it was crushed. Stamp mills ran relatively slow, and they could be driven by almost any power source, so many early

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(1979), Russell L. and Lyn Wood Mining History Archives.

[27] Richard O. Burt and Chris Mills, *Gravity Concentration Techniques* (Amsterdam, Oxford, New York: Elsevier, 1984), 5.

mills were built next to streams to use waterpower. Others were powered by steam engines.

A more advanced piece of equipment was the jaw crusher. Jaw crushers were patented in the United States in 1858, and they soon began to replace stamps and arrastras. The action of the jaw crusher is similar to the human jaw with one fixed and one moving plate of teeth. Run-of-mine ore is fed into the top as the jaws open, crushed as they close, and smaller chunks are discharged out the bottom into a bin as the jaws reopen. Jaw crushers typically discharge ore up to about 1" in size.

Gyratory crushers, developed in the early 1900s, used a continuous, rotary motion to produce an uninterrupted flow of still-finer ore. Virtually all have been driven by electric motors, usually through multi-belt drives. A gyratory crusher has a vertical cone that rotates and radially oscillates inside a fixed, tapered bowl with ribs or grooves. Chunks of ore entering at the top are churned and broken down as they pass from the wide annular opening at the top to the smaller discharge opening at the bottom. The gyratory crushers at Shenandoah-Dives were of two types, "standard head," which discharged ore as large as ½", and "short head," capable of crushing down to less than ³/₈". Typically, screens sorted the discharged ore by size. Large pieces caught by a screen were returned to the crusher inlet, and acceptable ore passed through to the grinding phase of the process.

Improved crushing and grinding systems, as well as the development of the flotation process, introduced a new trend in metals milling.[28] The flotation process required the ore to be a very fine, sandy powder, finer than anything even the best crushers could produce. Fortunately, new grinding mills became available during the later 1800s. Ball mills were large, rotating cylinders (drums) containing steel balls that pulverized the ore as it passed through the drum. A later variation, known as a rod mill, used a smaller-diameter drum and replaced the balls with metal rods. Some water was generally added to form a thick slurry. This grinding stage was crucial to the economic success of subsequent stages in the refining process. Grinding to a smaller size meant

[28] Pierre R. Hines, "Before Flotation," in *Froth Flotation 50th Anniversary Volume,* D. W. Fuerstenau, ed. (New York: American Institute of Mining, Metallurgical and Petroleum Engineering Incorporated, 1962), 9.

more surface area per pound of ore, which increased the likelihood that particles of the desired metals would be on the granular surfaces and, thus, more directly exposed to reagents in the subsequent flotation process. Entire mill operations were shut down periodically to improve the grind, whether by rearranging equipment in the process flow, replacing worn machinery, or by adding new devices to the plant's grinding circuit.

Ground ore then passed to a classifier that again sorted it by size. Any ore not ground finely enough was re-circulated for further grinding before it reached the concentration stage. The fine grind ore that passed classification made its way via chutes, pipes, elevators, and conveyor belts to the concentration stage.

Concentration greatly increased the value of ore by removing most of the non-metallic material to obtain the highest practical grade (concentration) of valuable metals. The two major methods to extract metals from ore were pyrometallurgy (smelting) and hydrometallurgy (flotation milling). During smelting, ores were heated until molten, and the components then separated because of their different melting points and densities. Milling could be achieved by several methods, with the most common methods of concentration being amalgamation, gravitation, chlorination, lixiviation (leaching), and flotation. Shenandoah-Dives and most modern mills employed flotation.[29]

Since the concentrated metal left the flotation stage as a suspension in water, the final step was drying. Typically, the suspension was first allowed to sit in large tanks where the solid particles would slowly precipitate out. Thick slurry containing these metal particles could then be dried further in vacuum filters, leaving a concentrate suitable for shipment to a customer, often a smelter.

A metallurgist chose the concentration method primarily for the mineralogy of the ore body to be processed but also for the available facilities, transportation, cost of smelting, cost of concentration method, amount of recovery, value of concentrate, and the contract between the seller and buyer. Smelting was the more expensive method, but it produced a higher-grade metal, so both methods were often employed in series.[30] Milling

[29] Lysa Wegman-French, "History of the Holden-Marolt Site in Aspen, Colorado: The Holden Lixiviation Works, Farming and Ranching, and the Marolt Ranch, 1879-1986" (Aspen, Colorado: Aspen Historical Society, October 1990), 13.

[30] A few processes utilize a third process, electroplating, to achieve even purer metal, but this is an expensive and time-consuming process that is seldom justified.

substantially reduced the volume of ore sent to the smelter. Developments in concentration technology have led to the obsolescence of some methods, but these criteria remain integral to the decision process.[31]

History of Flotation

As high-grade ores played out during the late nineteenth century, the mining industry had to confront the difficulty of mining complex (multi-metal) or low-grade ore bodies that contained smaller quantities of valuable metals. Of primary concern was how to economically separate these metals in quantities large enough to be profitable.

By the end of the nineteenth century, the development of the cyanide leaching process allowed low-grade-gold ores to be effectively concentrated into a gold product, but the industrial world had by then come to rely on many metals other than gold. In order to separate these non-precious "base metals," such as copper, lead, and zinc, the industry worked to develop a modern concentration method. Prior concentration methods (gravitation, smelting, and leaching) yielded two materials, a multi-metal concentrate and waste. As a result, these methods were ineffective in separating metals in complex mineral bodies. The industry badly needed a method for selective separation that would yield specific concentrates from such ores, and mining companies around the world raced to develop one.

Experimentation in the use of flotation on complex ores initially began in England in 1860 with William Haynes. The term "flotation" has been loosely used for all concentration processes in which heavier mineral particles have been separated from lighter waste particles in water by "floating" the valuable mineral away from the waste. Haynes found, when mixing powdered ores, oil, and water, that some minerals had a tendency to attach to certain oils, which floated on the water. By the end of the century, others experimented with such variables as additives (oils, acids, or salts), agitation, and heat. Flotation at these early stages was referred to as bulk oil flotation. Englishmen Francis E. and A. Stanley Elmore experimented with the use of both oil and agitation by paddles in the flotation process, which led to its commercial use world-wide at the turn of

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[31] *Flotation Fundamentals and Mining Chemicals* (Midland, MI: Dow Chemical Company, 1968), 91.

the twentieth century. Further improvements on their design led to the use of air bubbles to provide buoyancy for the metallic particles, which tended to adhere to the bubbles. Italian Alcide Froment is credited with this patent.[32]

Another type of flotation, referred to as skin flotation, did not use oils or agitation. Instead, dry ore was sprinkled gently onto the surface of still water. The heavier materials sank to the bottom, while the water's surface tension caused the lighter minerals to float on the surface, where they could be skimmed off. Subsequent improvements by Auguste de Bavay and Francis Elmore made the skin flotation process economically viable, although it experienced a limited commercial lifetime.

Independent experimentation based upon earlier patents at Mineral Separation Incorporated (M.S.I.) in Australia, resulted in the process recognized today as froth flotation. Following the reduction of ore to a fine product by crushing and grinding, it was introduced to one or more tanks of water to which oil had been added. Each tank had an array of small openings connected to an air source. The oil encouraged the small mineral particles to adhere to air bubbles rising through the tank to form a mineral-laden froth floating on the water's surface. The two-dimensional sketch in Figure 1 shows how fine metal particles adhere to the surface of air bubbles in this fashion. This mineral-rich froth was skimmed off, usually by rotating paddles, over a weir on the tank edge. For complex ores, several stages of flotation could be used, with different oils to capture different minerals. The froth bubbles collapsed as they passed over the weir, leaving a mineral-laden liquid, which was then dried to leave a solid concentrate for shipment to the smelter.

[32] This section on the history of flotation is largely drawn from Dawn Bunyak's National Park Service survey, *Frothers, Bubbles, and Flotation: A Survey of Flotation Milling in the Twentieth-Century Metals Industry* (Denver, CO: Government Printing Office, 1998).

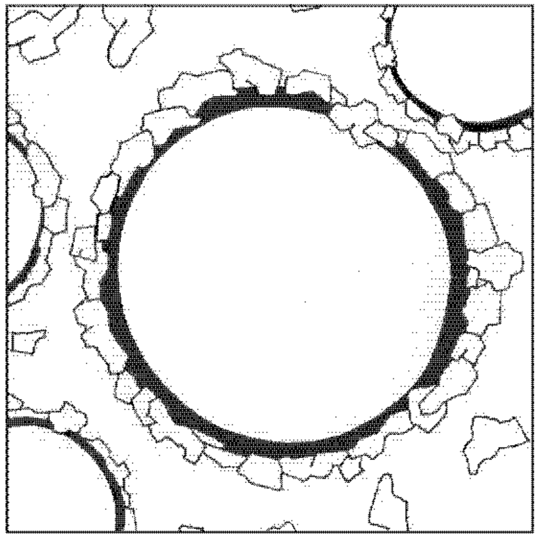

Figure 1. Two-dimensional sketch of metal particles adhering to the surfaces of air bubbles. In actuality, particles cover the entire surface of each bubble.

M.S.I. built the first successful commercial mill using froth flotation—now generally recognized as the "home of flotation"—in 1905 at Broken Hill, Australia. M.S.I. engineers E. L. Sulman, H. F. K. Pickard, and John Ballot soon filed a patent for froth flotation that used a small amount of oil in the ore slurry and agitation through a rising stream of air bubbles.

The persistent search for greater economy encouraged a series of innovations in concentration and crushing circuits. Theodore Hoover of M.S.I. devised the Minerals Separation Standard Machine for use in a complex flotation circuit. This machine consisted of a series of flotation cells divided into agitation and frothing compartments. Hoover designed the machine to pass the ore slime over a spitz box that introduced air bubbles into the agitation compartment, generating mineral-laden bubbles that rose to the surface. A rotating paddle in the frothing compartment collected the froth from the surface of the water. Since the machine had a series of cells, different cells could be set up to collect different metals. Although it was eventually superseded as improvements were made, Hoover's separation machine significantly advanced the efficiency of the flotation process by enabling the simultaneous separation of multiple products.

Improved grinding in ball and rod mills, along with better classifiers, increased the concentration potential by producing smaller, more-uniform ore particles for the flotation circuit. In addition, engineers continued to experiment with new, soluble frothing agents, commonly referred to as reagents, to increase frothing action and control the interaction between mineral particles, the bubbles, and the liquid in the cell. Isolation of a particular mineral depends on a delicate balance of acid and alkaline reagents in the flotation process. Appendix A lists the various reagents used at the Shenandoah-Dives Mill. Some were commercial products known by their trade names, while others were widely available chemical compounds.[33]

Flotation proved to be the most efficient means of mineral recovery to date. In it, the industry had discovered a means to exploit complex mineral bodies that were impossible to treat using earlier, gravity methods. Using flotation in the concentration process expanded production to twenty-four metallic and nineteen non-metallic products by the mid-twentieth century. Flotation can be used to process metallic (silver, copper, lead, zinc, and gold) or non-metallic (clay, phosphate, coal) ores, and it is now the most popular process in the world for extracting minerals. Without flotation, widely used base metals such as copper, lead, and zinc would have become increasingly costly and difficult to produce. Modern engineers and geologists assert that the evolution of the flotation process was the industry's most important development of the twentieth century.

Commercial Milling[34]

By 1929, when the Shenandoah-Dives Mill was built, flotation mills had become fairly standardized. Single-circuit plans continued to be useful in many regions where only one product was recovered, and complex mills allowed selective separation of more than one mineral by incorporating a series of flotation circuits. Complex mills were larger

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[33] Rather than accepting M.S.I.'s 1905 Broken Hill Mill as the birth of flotation, the chemical industry emphasizes its role by proclaiming that "modern" flotation actually began in 1923, when C. H. Keller discovered the use of xanthates as collectors for sulfide minerals at the Sunnyside Mill in Eureka. The chemists argue that this chemical mix significantly increased the concentration of metals, thereby increasing the efficiency of the flotation process and its economic viability. While undeniably true, this does not erase the fact that Broken Hill was commercially successful using earlier reagents.
[34] This section on the history of flotation is largely drawn from Dawn Bunyak's National Park Service survey, *Frothers, Bubbles, and Flotation.*

in size and generally processed larger quantities of ore, and in the following decades, mills continued to expand in size and processing capability. The Shenandoah-Dives Mill was an example of a complex mill capable of processing 750 to 1,000 tons of ore per day in a multiple-circuit plant that was reconfigured several times during its service life to produce a variety of products. It is a medium-sized mill designed to serve underground mines. With the rise of open-pit mining, mills grew exponentially to accommodate the massive increases in ore volume. Modern mills with milling processes in several buildings now cover several acres of land and process as much as 60,000 tons of ore per day.

Mill Building Designs

Terrain obviously influenced the mining landscape and mill architecture. Mill sites could consist of stepped buildings perched on steep mountain slopes, or of taller, compact mill buildings in flatter locations. Mines and mills were usually located in remote locations, although increasing urban development has made neighbors out of some towns and cities. While a location close to the mines offered obvious material-handling advantages, a good mill site also had to have reliable source of power and process water, as well as a means of economical transportation to smelter. In addition, a large, suitable area for disposal of tailings was essential if a mill planned to operate for any number of years.

Many twentieth-century flotation mills were efficient complexes designed by engineers to increase production, reduce the cost of operation, and maximize profits. These mills have ranged in size from small (50 to 100 tons per day) plants to huge industrial complexes capable of processing 60,000 tons per day. Geography, type of ore body, and the amount of ore being processed determined size. Earlier mills were constructed of wood, while later ones employed various combinations of wood, steel, and concrete. Engineers and metallurgists determined the type of milling process required for the particular ore, devised a process flow to achieve it, and selected the appropriate equipment. Finally, they designed buildings to house the operation, usually making allowance for future expansion.

Basic designs for mill complexes were drafted for slopes, level terrain, or a combination of the two. In mountainous regions, like Silverton, mills were built as multi-level buildings to allow gravity to move ore in its various states through the plant. The Shenandoah-Dives Mill is an example of a multi-level, or stepped, building. Mills on level sites generally were taller and more compact in plan, but these plants had to use more powered machinery to move product through the milling process. Mills fortunate enough to have both inclined and level sections could use gravity in stepped crushing and grinding stages, but their flotation equipment could be located on flat ground to minimize pumping requirements.

In addition to the process equipment, numerous systems were needed to support mill operations. They included tramways, railroads, or roads for ore delivery; arrival and shipping terminals; ore bins; conveyors; power and water service; administrative and operations offices; and ancillary buildings for storage, workshops, laboratories, and washrooms. Tailing ponds for the disposal of process residue were also essential, and they are still evident around most mill (and smelter) sites. They can cover dozens, or even hundreds, of acres.

CHAPTER 6: MILLING TECHNOLOGY AT THE SHENANDOAH-DIVES MILL

The Original Mill (1929-1934)

The Denver-based company Stearns-Roger Engineering designed and oversaw the erection of the Shenandoah-Dives Mill. Construction began June 19, 1929, on a multi-story, stepped building on a mountain slope about 2 miles east of Silverton, Colorado. It was terraced into the mountainside to utilize gravitational flow within the mill wherever possible. Arthur J. Weinig designed the metallurgical portion of the mill, and he worked at the mill for several years thereafter.

Laborers first located the footprint of the multi-story building on the side of the mountain, manually excavated as necessary to establish level floors, built wooden forms, and then poured the concrete floors and foundations of the mill. They built the mill in eighteen weeks from what was essentially a kit of parts made off-site.[35] The mill building's framing and roof trusses arrived as a pre-fabricated kit, and carpenters pieced the numbered pieces together like a puzzle around the mill equipment. The process equipment for the mill also arrived by train to be positioned as Weinig directed. Men, animals, and simple cranes hoisted heavy boilers, motors, and ball mills into place. Other workers assembled various bins and tanks, as well as the lines of rougher, cleaner, and scavenger cells in the flotation area.

As built, the timber frame of the building was constructed of Oregon fir over a concrete foundation with native timber for wall sheathing. The rooflines included gable and shed roofs covering the four levels. The exterior was initially whitewashed, but painted aluminum in 1932.

Early photographs depict the construction process, including showing mules hauling planks to framers located at the upper portion of the main building and to those working on the conveyor section. A photographer from the Salt Lake City (Utah) *Mining Review* took a panoramic view of the mill. While this photograph survives, it is not evident that an article was ever prepared to accompany it.

[35] Due to the evidence of archival photographs and the speed of the mill's erection, it appears that the mill framing was designed and pre-cut in Denver, bundled up, and shipped to Silverton for erection by the construction crew. For more history on the Shenandoah-Dives Company, refer to Dawn Bunyak, "The Shenandoah-Dives Mining Company," *Colorado Heritage* (May 2003), 35-45; Bunyak, *Frother, Bubbles, and Flotation*; Silverton HD NHL, 1966; and U.S. Department of the Interior, National Park Service, Shenandoah-Dives Mill National Historic Landmark, 16 February 2000. This section was drawn from these works unless otherwise noted.

Figure 2. The Shenandoah-Dives Mill under construction in 1929. Note mules with planks balanced on their backs. (Courtesy of San Juan County Historical Society)

Some ancillary structures were necessary as well. In addition to the mill building, three wooden-stave tanks were constructed for storing water and coal. Two of these tanks still exist. Early photographs from the 1930s show a smaller, almost-round building situated just above the mill building, but no known correspondence or mine report identifies it. This building is no longer extant, and its use is now unknown.

While the mill was under construction, yet another crew built a 10,594' aerial tramway from the mine to the mill. The Walker Art Studio made several photographs of it between 1934 and 1941. The Iowa Tiger Mill tramway-loading terminal was rebuilt and re-routed for use by the new system, with a new discharge terminal at the new mill site. The tramline began transporting ore to the mill in January 1930, carrying in excess of 170,000 tons that year.[36]

[36] "Bureau of Mines Inspection Report, State of Colorado for the year 1930: Metals, Mines and Mills," (San Juan County, Animas District), 1930-1931. Since its closure, the Bureau of Mines' reports are available at the Colorado Division of Minerals and Geology, Denver, Colorado.

Figure 3. The tramway terminal as it appeared in 2005. The wooden tower held a weight that maintained tension in the traction cable. (Dana Lockett, HAER Architect)

The new tramway terminal at the mill was a rectangular, single-story, frame and metal building with a gabled roof. It was originally built as a stand-alone building on the side of the mountain east of the plant, but was later connected to the main building with the addition of the crushing plant, whose construction enclosed the rear of the tramway terminal leaving it essentially intact. The approximately 25'x58' terminal retains the original set of four six-over-six double-hung windows on the east wall and is now clad and roofed in corrugated metal. A timber structure supports the building and elevates the floor above the sloping ground. The southeast end is open to allow the entrance and exit of tram cables and ore buckets. Entering ore buckets would roll from the tram cable onto an overhead monorail, where men would push them to a spot over a hopper at the back (northwest end) of the building and rotate the bucket horizontally to dump the ore. They would then push the bucket on around the monorail, where it would re-engage the cable for its trip up the mountain. The tram terminal also included an adjacent wooden tower to support a large weight used to maintain tension on the traction cable and the shop for tramway bucket repairs.[37] Fred C. Carstarphen, who designed the tramway and terminals, also directed the crew that constructed the system. When the aerial tramway was functioning, stationary and traction cables ran approximately 10,594' from the lower terminus at the Shenandoah-Dives Mill to the mine's upper terminal building.[38]

The tramway's ore buckets traveled along a 1⅜" stationary cable, pulled by a ⅞" traction cable. Many aerial trams used a single moving cable to both support and propel their buckets, but Carstarphen chose to use separate support and traction cables due to the steep incline. He also designed four-wheel trucks for these buckets instead of the industry's standard two-wheel trucks. The tramway normally carried fifty-two ore buckets, two timber carriers, and one automatic cable oiler. Two sizes of ore buckets, 17 cubic feet and 21 cubic feet (cu. ft.), were spaced at intervals of approximately 400'. Each 21-cubic-foot bucket had a round bottom and carried one ton of ore, while the smaller ones had angled bottoms and carried 1,600 pounds of ore. When the tramway was running at full speed, a bucket took forty-five minutes to make a complete cycle from the mine to mill and back again.[39]

Two 50-horsepower General Electric motors that were originally located at the upper terminus of the tramway drove the traction cable. Their primary function was speed control. Since the loaded, descending buckets were considerably heavier than the empty, ascending ones, this weight differential allowed gravity to furnish most of the driving force. The endless traction cable passed around two, 6'-diameter grip sheaves at the upper terminal. One 50-horsepower, constant speed motor was connected to one of the grip sheaves. The second sheave was connected to the second motor, a variable-speed motor that could be used like a brake. It could also reverse the tramway's direction of operation, which was occasionally needed to solve problems. Together, these two motors could control the tramway's speed or completely stop it when necessary.[40]

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[37] Courtney Gunderson, summer field team, e-mail correspondence, 9 August 2005.
[38] Mining historians Douglas and David Thayer conducted a survey of all tramway systems in the area of Silverton and determined in 1999 that the length of the tramway is approximately 10,594', despite dimensions of approximately 9,500' given in earlier publications describing the construction of the aerial tramway. Correspondence from Doug Thayer, mining historian, dated 19 November 1999. For more information on the construction of the aerial tramway consult "Shenandoah-Dives, Part Two."
[39] "Shenandoah-Dives, Part Two."
[40] "Shenandoah-Dives, Part Two."

Figure 4. One of the ore buckets on the tramway just outside the tram terminal. The bucket rolled along the stationary upper cable and was pulled by the lower traction cable. (Dana Lockett, HAER Architect)

At the mine's loading terminal, (unfortunately no longer in existence) an arriving, empty bucket was automatically diverted from the support cable onto a monorail. As the transfer took place, a fixed, cam-like device known as a camel released the bucket's grip on the traction cable. Curved rails on the camel engaged and moved a lever on the bucket's truck to release the clamping load as it passed by. Operators then pushed the bucket along the monorail to the loading chute, where they secured it with a chain for safety during loading. Once full, the operator pushed the loaded bucket further along the monorail, changing direction 180 degrees in the process, to a point where a second camel moved the bucket's grip lever back to engage the traction cable. The traction cable then pulled the bucket smoothly off the end of the monorail and onto the support cable for its trip down the mountain. The ingenious camel made engagement and disengagement of the traction cable automatic, positive, and safe. A similar process occurred at the mill's receiving terminal, except that here the buckets were unloaded instead of loaded.[41] The bucket spacing and cable speed (500' per minute) were such that the operators dispatched one bucket from each terminal just as another arrived.

As originally built, a total of fourteen intermediate towers supported the tramway. Departing from common practice in the region, Carstarphen used steel instead of wood in the design for these towers, which not only made for a stronger tower but also required that fewer be constructed. Carstarphen chose steel as the building material because he thought they would be more resistant to the area's heavy snowfall and frequent avalanches. Built by the Pittsburgh Engineering Company, the towers featured riveted construction and rested on a concrete foundation. Eleven of the towers (Towers 1 – 11) supported and guided the tramway's support and traction cables, but three of them (Stations A, B, and C known as double-cable anchor stations) also helped maintain the tension of the support cables, which were anchored to bedrock at each terminal. In spite of their rugged construction, avalanches twice knocked down some of the towers near the upper end. An avalanche diverter was built above Tower 1 after an avalanche destroyed Towers 1 through 5 in 1938. It worked to protect Towers 1 and 2 during a severe avalanche in the winter of 1963-64, but that event destroyed Towers 3, 4, and 5. The tramway was obsolete by this time, and the Shenandoah-Dives Mine was being closed anyway, so the tramway was not rebuilt. Fortunately for history, however, the remaining tramway components were left in place.[42]

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[41] "Silverton Historic District NHL (Boundary Increase), San Juan County, Colorado," 1997.
[42] "Shenandoah-Dives, Part Two."

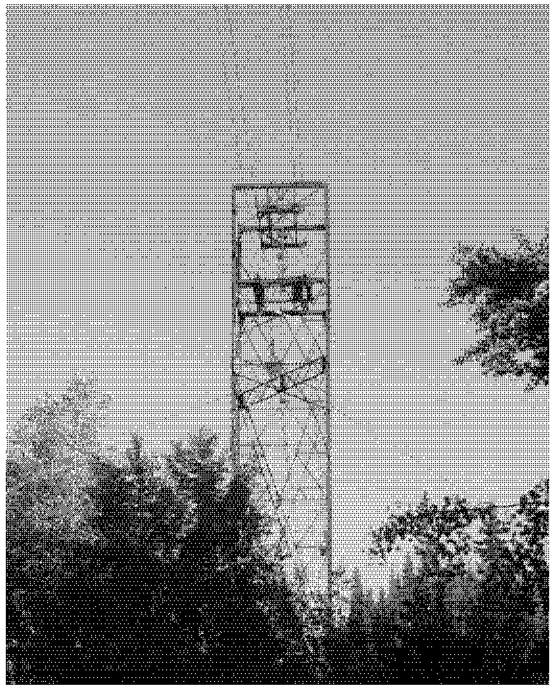

Figure 5. One of the surviving tramway towers. Note that the ore buckets passed through the top section of the tower. (Dana Lockett, HAER Architect)

In the case of the Shenandoah-Dives Mine, all of its ore initially came from the company's own mine in Arrastra Gulch via the cable tramway. The primary crushers were located underground at the head of the mine (to permit year-round operation), so the material arrived at the plant crushed to about ½" in size. Once delivered to the mill by the tramway, the roughly crushed ore traveled up a 200'-long inclined conveyor to the ore bin, and from there through another crusher and on to the No. 86 Marcy ball mill. This device, a wet-crushing mill, was the final stage in the fine grind circuit, and it consisted of a horizontal cylinder rotating on a pair of trunions and driven by an electric motor. Water was added to the dry ore at this point to make a slurry known as "slime pulp," or simply "slime." The slime flowed into one end and passed through the revolving cavity filled with steel balls that pulverized the ore particles. The discharge end was fitted with a screen that collected coarse material to be reground and steel balls that had worn down enough to be carried by the slime. The No. 86 Marcy ball mill used at Shenandoah-Dives could process up to 1,000 tons of ore in twenty-four hours with a normal charge of balls weighing approximately 28,000 pounds.[43]

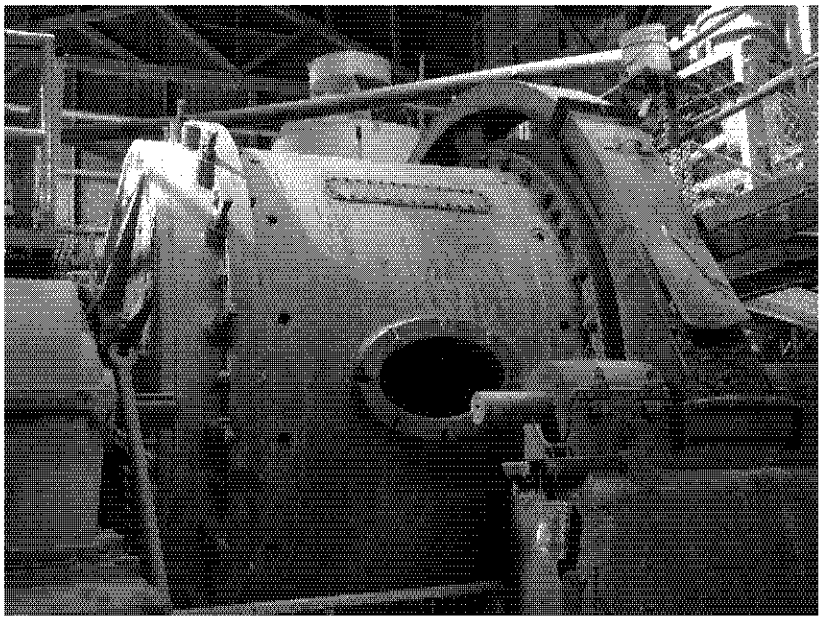

Figure 6. The Marcy No. 86 ball mill. The oval opening, used to add balls, was covered during operation. (Dana Lockett, HAER Architect)

Proper grinding turned out to be crucial to successful flotation. Fine sand, as acceptable material was known, in the slime consisted of grains between 0.125 and 0.25 millimeter. Sand with larger grains was called coarse sand, and it had to be separated and reground until grain size was proper for the flotation circuit. Several modifications were made in this area over the years to improve the consistency of the sand passed to flotation but minimize the amount needing to be reground. At various times a second, and even third, ball mill (Stearns-Roger No. 65 and Stearns-Roger 4' x 10') would be used in the regrind circuit. Several flow sheets show these ball mills introduced, but later removed, at various times during the mill's active life.

Charles Chase reported in the 1931 Mine Report that increased ore tonnage—slightly above the design capacity of the mill—caused serious losses from inadequate

[43] "Marcy Ball Mill," *Catalog No. 72* (Denver, Colorado: Mine and Smelter Supply Company, 1926), 8. The catalog collection is housed in the Russell L. and Lyn Wood Mining History Archives.

grinding. These problems were alleviated with the addition of a 12'x6' Dorr classifier to the crushing and grinding circuit. This classifier allowed only acceptably fine material through. Rejected ore was recycled back through the grinding circuit.

The ground-ore slurry from the ball mill passed to one of three No. 6 Wilfley tables, vibrating tables with small grooves and a slight incline that performed the last purely mechanical separation. As a thin sheet of slurry flowed across the shaking table, the heavier, metal particles tended to collect along the lower edge, while the lighter material and water passed off the table. This concentrate, consisting of several metals, was then dried and dumped into a bin to await shipment, while the remaining material passed on to the flotation stage of the process.

In January 1932 Chase reported on the progress of the mining company to the syndicate in Kansas City, "We are the fortunate beneficiary of advance knowledge of Mr. Weinig's remarkable studies of ore grinding, and conclude that we shall be able to grind to correct fineness much higher daily tonnage than the present record maximum of 584. Provision of additional Dorr classifier equipment seems the major probable equipment." Chase realized that the "maximum economy at the mine lay in operating at capacity of the plant."[44] That year the company produced: gold (30,532 oz.), silver (408,755 oz.), lead (1,002,849 oz.), and copper (1,480,300 oz.).[45]

Over the next several years, improvements to the grinding circuit included 4'x10' and 6'x5' (overflow) Stearns-Roger ball mills; a Symons short-head crusher installed before the Marcy ball mill; and a spiral-frame trommel screen after the ball mill. Notations in mine reports between 1931 and 1935 revealed "serious problems with crushers, problem solved" with improvements. The mill's earliest flow sheets (schematic drawings of the process flow) do not include the order of equipment in the crushing plant, but the flow sheet in Figure 7 shows the process after most of the initial improvements. Of particular interest in the early flow sheets is the wet bucket elevator. Material-handling machinery such as this was usually omitted from flow sheets, but this use of an

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[44] Quotes from Charles Chase's report, "Shenandoah-Dives Mine, San Juan County, Colorado, January 1932," on the progress of the mining company to the Syndicate in Kansas City. The report is in the Russell L. and Lyn Wood Mining History Archives.

[45] Chase, "Shenandoah-Dives Mine, San Juan County, Colorado, January 1932."

elevator instead of a pump to raise the material about two stories suggests that the slime at this point was fairly dry during the mill's early years, even though a substantial portion of it was overflow from the Wilfley tables. Although several process changes over the years would seem to have raised the water content of the material it handled, the wet bucket elevator remained in service until its removal in the 1980s.

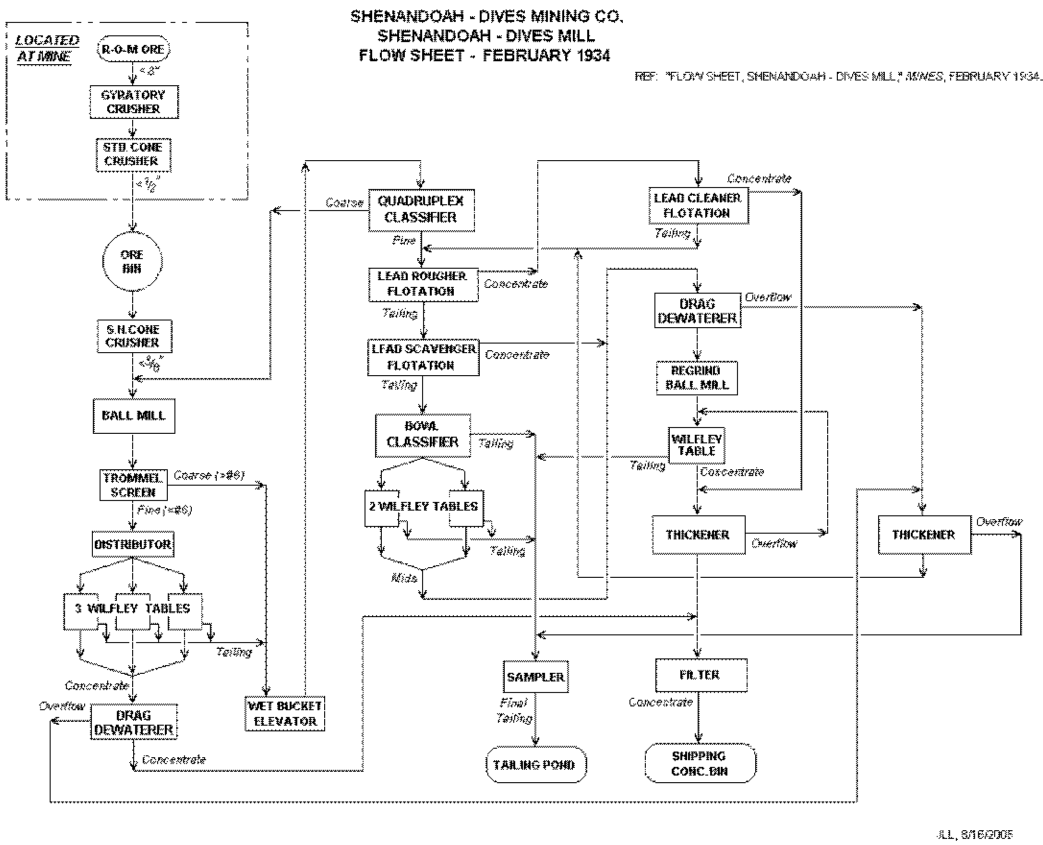

Figure 7. Shenandoah-Dives Mill 1934 flow sheet. This is based on a flow sheet of the Shenandoah-Dives Mill published in *Mines*, February 1934

Slime from mechanical separation then passed to the flotation stage of the process, where metals were selectively separated as the slime circulated through a series of flotation cells with water chemically treated to promote the separation of specific products. In order to achieve maximum separation, an optimum point had to be met and maintained. Variables considered were particle size, reagent additions, slime density, flotation time, temperature of the slime, and the type of circuit used. The grind had to be evaluated for the uniformity of size, settling and filtration properties, corrosion and erosion potential, and finally, its particular mineralogy. Adjustments and testing were ongoing to obtain the greatest yield.[46]

An interconnected series of flotation circuits known as roughers, cleaners, and scavengers introduced slime from the grinding stage into a water bath. This slime was a complex mixture of finely ground minerals and gangue (waste) mixed with additional water and lime to create a slurry called "milk of lime." Reagents to drive the separation, frothing agents to promote bubble formation, and chemicals to control the acidity of the slime were added as appropriate at each stage of flotation.

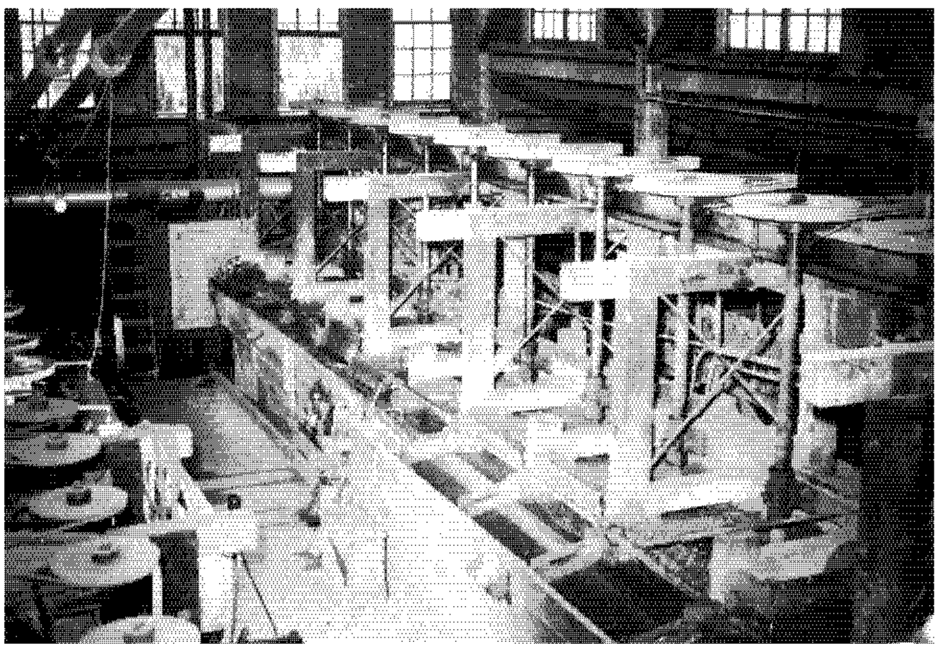

Figure 8. Some of the earliest flotation cells at Shenandoah-Dives, ca. 1930.
Nine cells of one row are fully visible, along with agitator drive sheaves
for a second row at the lower left. (Courtesy of San Juan County Historical Society)

Complex flotation circuits, like those employed at the Shenandoah-Dives Mill, generally consisted of three types of cells: rougher, cleaner, and scavenger. Although the

[46] Adrian C. Dorenfeld, "Flotation Circuit Design," in *Froth Flotation 50th Anniversary Volume* (New York: American Institute of Mining, Metallurgical and Petroleum Engineering, Incorporated, 1962), 365, and "Flotation Process," *Catalogue No. 72* (Denver, Colorado: Mine and Smelter Supply Company, 1926), 24.

specific chemical compositions of the water baths in the three types of cells were tailored to suit the parameters of the water bath and its metals at each point, all flotation cells operated basically the same way. As a rotating agitator churned the mix, low-pressure air injected into the cell produced air bubbles. Oil in the water bath quickly formed a film on these bubbles, and metal particles in the water were attracted to the oily bubbles. Various reagents promoted or depressed this attraction for specific metals in the various cells. The bubbles floated to the surface, forming a mineral-laden, frothy foam with a metallic appearance. As new mix was added, and aided by rotation paddles, these bubbles fell over the edge weir of each cell into a launder trough and collapsed into a liquid with a higher concentration of metal. The sandy, water-soaked gangue sank to the bottom of the cells, where it could be pumped out.

In a complex circuit, the concentrate in the launder trough was pumped to the next stage of cells, or on to dewatering. The gangue was routed to another set of cells, back to a grinder, or ultimately to the tailing discharge. The precise sequence of cells for both concentrate and gangue varied, depending on the ore body and desired products.

Reagents added to the slime to facilitate separation fell into three classes: collector (attracted a specific metal to bubbles), depressant (sank a particular metal in the water bath), and frother (aided in forming air bubbles). The first frothing agents were pine oil, creosote, eucalyptus oil, and oleic acid. Later frothing products included polypropylene glycol methyl ether and commercial formulations known as Aeroflots. They could be added at the rod- or ball-mill stage, or just before the flotation circuit. Depending on the assay, or analysis, of the ore body being processed, soluble salts and other reagents were added at various stages in the process to obtain the best yield of the desired metals.

As in most mills, rougher cells were the first stage of the complex flotation circuit at the Shenandoah-Dives Mill, and they primarily removed the bulk of the gangue from the ore. From the rougher cells, the rough concentrate went to cleaner cells that increased the concentration and removed the rougher reagents. In some cases, re-cleaner cells, secondary cells for the re-treatment of the concentrate from the primary cleaner cells, were employed for additional concentrate refinement. From here, the concentrate traveled through a series of dewatering devices that rendered it a "damp cake" suitable for shipment to a smelter.

The gangue from the rougher cells flowed to scavenger cells.[47] Scavenging was the final stage in flotation to remove for retreatment as much of the low-grade metal, which was still in a frothy state, as possible given the conditions. Scavenger cell concentrate was reintroduced into the rougher circuit, while this gangue, or final tailing, was pumped to the tailings pond, where it dried into a solid waste that remains in place.

To produce a damp cake, concentrate from the cleaner cells first flowed into thickeners. These were large, vertical tanks with slowly rotating blades or rakes where the solids could precipitate out of the water, gradually settling on the bottom. As the blades rotated, they gently moved this precipitate to an opening in the tank bottom, through which it passed as thick slurry with most of its water removed. As new concentrate was added, the overflow water was collected in a trough at the lip of the tank.

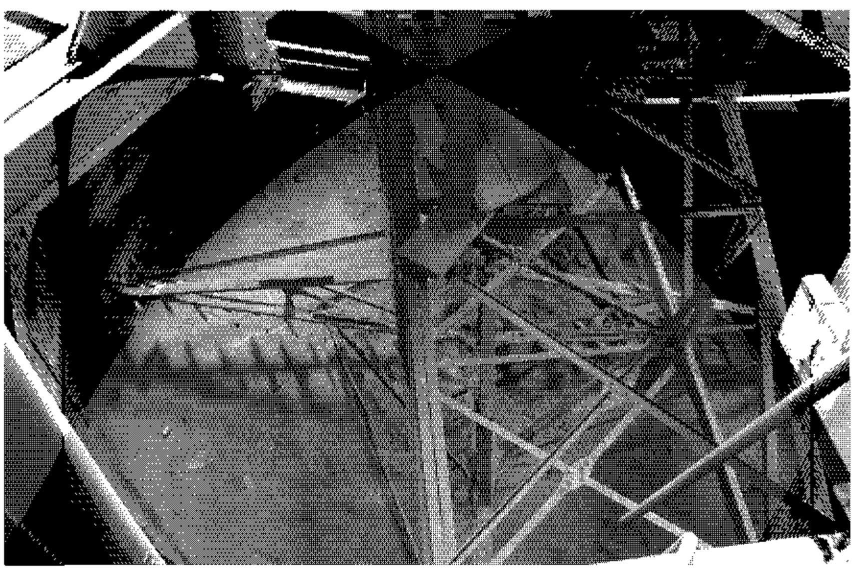

Figure 9. View looking down into one of the two Dorr thickeners as they appeared in 2005. (Dana Lockett, HAER Architect)

[47] Gangue flowing from flotation cells is sometimes referred to as "tailing," a term primarily reserved for the final waste material from a mill or smelter but that may be more generally used for almost any type of waste, or incompletely processed material, at various points during the concentration process.

From the thickeners, the thickened slime was pumped through vacuum filters to remove more water. The Shenandoah-Dives Mill used an Eimco drum filter and disc filters made by Denver and Eimco. Both types operated on the same principal. The thickened concentrate flowed into a tank containing a horizontal, cloth-covered drum or discs that revolved slowly, about half submerged in the concentrate. A vacuum inside the drum or discs sucked out the remaining water, leaving the solid metal concentrate attached to the canvas. The solids caked to the cloth were scraped off, or dislodged with a blast of compressed air behind the cloth into the concentrate bin below, where it remained until being shipped to a smelter. In a complex circuit like that in the Shenandoah-Dives Mill, more than one concentrate could be produced simultaneously. This necessitated flow separations at certain points in the flotation process, as well as separate dewatering and filtration circuits for the different concentrates and separate collection bins.[48]

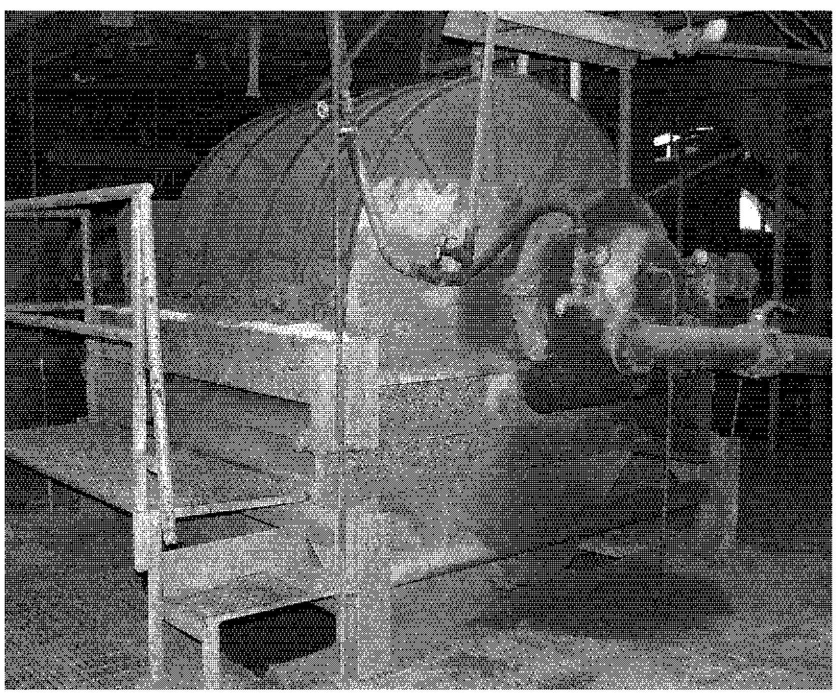

Figure 10. The Denver disc filter. The mill's two Eimco disc filters are similar, but contain fewer discs. (Dana Lockett, HAER Architect)

[48]Paul W. Thrush, *A Dictionary of Mining, Mineral, and Related Terms* (Washington, DC: U. S. Department of Interior, 1968), 330.

The products produced at the Shenandoah-Dives Mill varied over the years, so the flotation process was modified numerous times to suit the desired products, employ more modern equipment, and accommodate changes in how raw ore arrived at the mill.

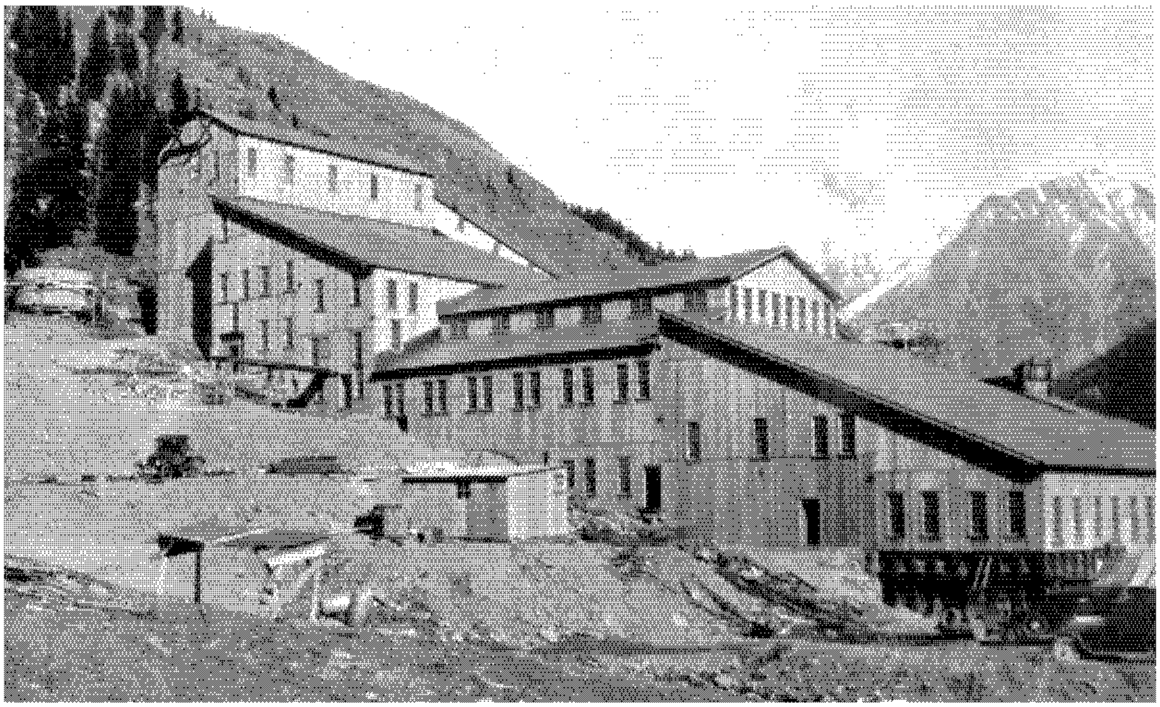

Figure 11. The newly completed Shenandoah-Dives Mill in October 1929. (Courtesy of San Juan County Historical Society)

The First Round of Changes (1934-1942)

The Shenandoah-Dives Mill had come on-line just as the Great Depression struck, but the company managed to keep the mine and mill open for the most part while Chase and his men worked to solve the inevitable start-up problems. In spite of the difficult economy, they were successful enough to avoid bankruptcy. Some of the early improvements at the mill to get it running efficiently have already been noted, but as recovery programs began to stimulate some demand, the desired products changed and more-specific separation was required. This was a recurring theme in the industry, and additional improvement and modification programs took place over the years to cope with the changing market. These programs are best grouped into periods, the first of which occurred during the mid-to late-1930s.

For its first five years, the mill sent its tailings down the Animas River, polluting the waters below the plant. In 1934, after researching methods that were believed to be environmentally sound, General Manager Charles A. Chase decided to use an innovative tailings-pond method perfected and utilized by J. T. Shimmin in Butte, Montana. Altering this method to fit the Shenandoah-Dives Mill's specific needs and terrain, the Shenandoah-Dives Mining Company began depositing its waste into tailings ponds south of the mill in mid-1935.

At the time, the utilization of tailings ponds was atypical for the mining industry as a whole. Generally, environmental concerns were not at the forefront of the industry's interests; profitable veins of ore were of greater concern. As a result, the Shenandoah-Dives Mill was one of a limited number of mining enterprises that employed environmental, as well as cost-efficient, methods in their day-to-day activities.[49]

The tailing slurry was pumped from the scavenger cells to the upper end of a V-shaped flume that delivered the tailings to the pond area. The flume was made of two 2" planks; one 12" wide, and the other 10" wide. Supported by a 20'-high trestle, it was set on a gradient so the tailings would flow downhill by gravity. Upon arrival at the pond, a 20'-long, grooved board distributed the tailings to form a "wall of sand" in the shape of pond. A technician would move the board periodically to retain a level top to the pond. In order to draw off, or decant, water without stirring up the sediment, a wooden box was laid in an inclined trench up the hillside prior to depositing the tailings. The top of this box had a series of holes $1^1/2$" in diameter. As the water level rose, the lowest hole was corked off to elevate the water level. As each subsequent hole was reached, a cork was placed in that hole. Once the desired level of water was attained, pipes drained off the water into a decantation pond, located on a lower plane than the tailing ponds, where it could evaporate. In practice, only a small portion of the water was actually decanted and

[49] Duane A. Smith, *Mining America: The Industry and the Environment, 1800-1980* (Kansas City, Kansas: University of Kansas Press, 1987), 34-41.

evaporated. The greater volume percolated into the hillside.[50] As each tailing pond filled to capacity, the flume was lengthened and another pond was begun. At the Shenandoah-Dives Mill, the ponds filled a triangular shape, following the mill's property lines. Two areas of tailing ponds were created over the next two decades.

Figure 12. This aerial view of mill ca. 1936 shows the elevated flume to the tailing pond running up from the center of the mill and turning toward the tailing pond out of the picture to the left. (Courtesy of San Juan County Historical Society)

These early tailing ponds were a vast improvement over dumping tailings into the river, but they did not completely solve the pollution problems. Though the process was not fully understood at the time, water percolating into the hillside had often leached a variety of chemicals out of the finely ground tailings, and these could ultimately find their way into the local aquifer. Changes in public awareness and government attitudes

[50] Charles A. Chase and Dan M. Kentro, "Tailings Disposal Practice of Shenandoah-Dives Mining Company," in *Mining Year Book, Mining Congress Journal* (Denver, CO: Colorado Mining Association, 1937), 31-32 and 74-76; and Charles A. Chase and Dan M. Kentro, "Tailings Disposal Practice of Shenandoah-Dives Mining Company," *Mining Congress Journal* 24 (March 1938): 19-22. In this article, they argue the cost efficiency, as well as environmental benefits, of using tailing ponds instead of other methods of disposal.

over time resulted in serious environmental legislation during the 1970s that mandated technological improvements in future tailing ponds at the mill site.[51]

In August 1936, Chase added a custom-ore crushing and sampling plant adjacent to the tramway terminal. The custom-ore operation allowed the mill to process ore for other Silverton-area mines and generate additional revenue for the mill. In that first year, a reported fourteen mines trucked in ore, but the total tonnage of custom ore processed was not recorded. In a 1940 Report of Operations, however, Chase recorded only 49 tons of custom ore processed during the first three months of the year. Limited information is available regarding the custom-ore operation at the Shenandoah-Dives Mill, but oral interviews indicate that it was a short-lived venture. The high building with the cupola partially obscured by the inclined conveyor in Figure 12 is believed to be this sampling plant. How the custom ores moved from their receiving bins to the sampling plant and from there to the fine ore bin is not apparent from the photograph or inspection of the mill as it currently stands.

As the crushing and grinding circuits were improved, Weinig hired flotation consultant Fred A. Brinker to review the flotation circuit and make improvements. Brinker suggested a redesign of the process to enable selective lead-copper and zinc concentrates recovery instead of the bulk product (lead-copper-iron) initially produced. In collaboration with new Mill Superintendent E. C. Wheeler, Art Yahn, and Daniel M. Kentro, Brinker designed selective-flotation circuits that accomplished this and increased the mill's capacity from 300-500 to 700-725 tons per day.[52] In addition, they suggested that a second ball mill be added to the fine-grind circuit. In 1937, the fine-grind circuit area was expanded south to provide room for this ball mill. The flow sheet in Figure 13 includes these improvements and process changes. Photographic evidence from this period suggests the area also provided space for the maintenance of small engines and electrical equipment.

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[51] Jones, "History of Mining and Milling Practices."
[52] William Jones, correspondence to Dawn Bunyak, 6 April 1996. Jones provided an extensive time line created from his research of Mine Reports submitted by Chase to the State of Colorado. Jones owns the Charles A. Chase Collection that includes reports, photographs, and correspondence of Chase's years as General Superintendent at the helm of the Shenandoah-Dives Mining Company.

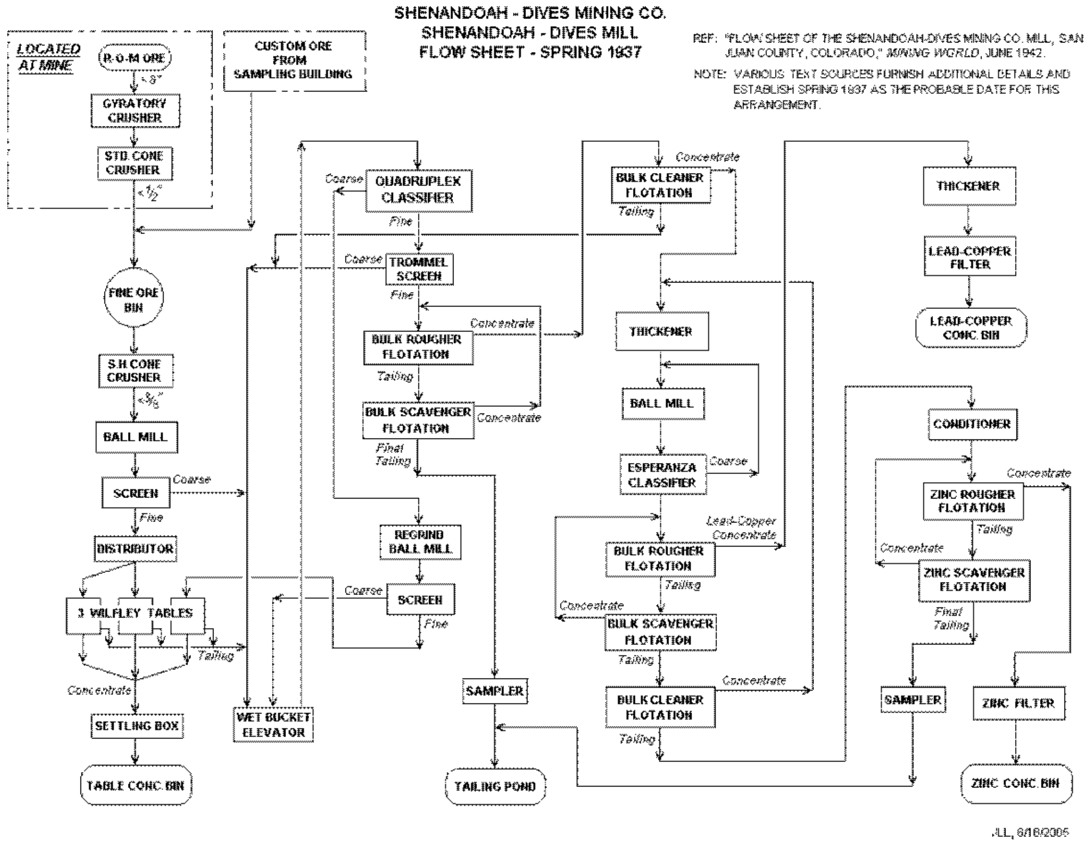

Figure 13. Shenandoah-Dives Mill 1937 flow sheet. This flow sheet is based on a flow sheet of the Shenandoah-Dives Mill published in *Mining World*, June 1942, but various text sources and Jones' time line point to this being the arrangement at least as early as spring 1937.

The sulfide ore mined in San Juan County was a matrix of metallic and non-metallic minerals, sulfur, and oxygen. Metallic sulfides, except for sulfides of alkali metals, are generally insoluble in water.[53] For the flotation process to work with this ore, the slime had to be conditioned through the addition of soluble alkaline sulfides in the water bath to sulfidize the desired base-metal minerals. (The sulfur was later separated from the metal in the smelting stage.) At this point, collector reagents were added to float the base-metal minerals from associated minerals found in the ore body. Reagents classed as depressants "sank" the unwanted associated minerals. Frothers were added to prolong the life of the mineral-laden bubbles in the flotation circuit. In the early years, the water

[53] Thrush, *Dictionary of Mining*, 1100.

was acidified with sulfuric acid, and pine oil served as a frother.[54] The metallurgists at Shenandoah-Dives Mill also used commercially produced xanthates (first patented in 1925) as reagents, which allowed a zinc concentrate to be produced. In addition, small amounts of cyanide were used to depress, or sink, iron pyrite minerals in the flotation process.[55]

Once the metallurgist had determined the feed rates needed, these reagents had to be continuously and precisely metered into their respective water baths to maintain the proper concentrations. For most of its life, the Shenandoah-Dives Mill accomplished this with metering pumps designed by J. Robert Clarkson, a creative miner, plant operator, and inventor.[56] He developed his Clarkson Liquid Reagent Feeder during the mid-to-late-1930s, and the unusual device soon earned an enviable reputation for consistency and reliability, becoming a staple in the minerals industry.

The Clarkson Reagent Feeder was basically a small water wheel with cups—Model E used by Shenandoah-Dives had seven—spaced around the wheel. With the vertical wheel partially immersed in a vat of reagent, the cups picked up the liquid and raised it as the wheel turned at a constant speed, driven by a small electric motor. Near the top of the arc, the cups tipped over enough for reagent to spill out onto a set of three chutes. The lowest, fixed chute caught the first few drops of reagent that spilled somewhat erratically from the cups and returned them to the vat. The upper chute was adjustable, and the liquid it captured, the last to spill out, was returned to the vat as well. A fixed chute in between these two captured the remaining reagent and routed it through a tube to a flotation cell. A float valve maintained the reagent level in the vat. While this might seem to be rather convoluted, the feeder actually worked quite well in practice.

[54] Root & Norton Assayers, "Mill Chemicals: Description, Use & Purpose, 1991," unpublished typescript.
[55] Small amounts of cyanide were used in the milling process until 1991. Jones noted that the tailing ponds' water was treated as "discharge regulations" became more stringent, in "History of Mining and Milling Practices."
[56] Clarkson never worked for Shenandoah-Dives. He began his career as a mucker in an Idaho mine, went on to manage several milling operations in the West, and ultimately founded The Clarkson Company to manufacture and market the feeder he developed and other milling specialties. He was inducted into the National Mining Hall of Fame in 1999.

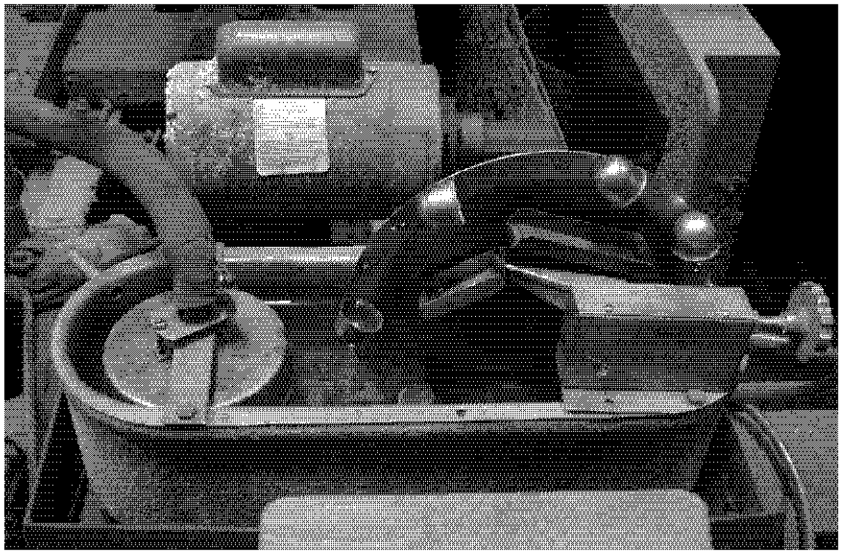

Figure 14. Clarkson Model E reagent feeder. The hand wheel at the right adjusts the position of the top chute and, thus, reagent flow to the flotation cell. (Dana Lockett, HAER Architect)

In 1937 Superintendent Wheeler died suddenly, and Arthur Yahn replaced him. At the same time, Dan Kentro became metallurgist at the mill, and he continued to make improvements in the flotation circuit that soon made it possible to separate a copper concentrate. By early 1938, the mill produced separate lead, copper, and zinc concentrates, and the company reported to the Bureau of Mines that forty-six men worked for the mill with another 183 in the underground mine.[57]

More Changes to Meet Wartime Demands (1942-1953)

The World War II and Korean War eras saw a high demand for all metals, including those produced by Shenandoah-Dives, and the mill enjoyed a period of relative prosperity, though not without some difficulties. Wartime labor shortages hampered plans to further modernize the flotation circuit; however, the company was able to add new Fagergen flotation cells to the rougher circuit in 1943. Due to steel shortages, these cells were made of concrete. A set of Denver Sub-A cleaner cells was installed in the lead circuit the following year.

[57] Jones Outline and "Bureau of Mines Inspection Report, State of Colorado for 1937: Metals, Mines, & Mills," (San Juan County, Animas District January 1938).

The high demand for basic materials during wartime usually drops drastically soon after the conflict ends, but this did not happen after World War II. After two decades of deprivation due to depression and war, consumer demand for goods and infrastructure supported the transition into a robust peacetime economy. Accordingly, the demand for metals remained high. At Shenandoah-Dives, custom-ore processing actually peaked in 1946 due to the high demand—and prices—for lead and zinc.

While production surged during and immediately after World War II, infrastructure improvements in the San Juan Region changed some aspects of the industry, especially transportation. The federal government's support for a significant road-building program was key. Highway 550 was vastly improved, and trucks began to haul ore directly to smelters instead of the railhead in Silverton. As car loadings dropped, the Rio Grande Railroad's revenues and services declined dramatically, and it ultimately abandoned freight service over its entire narrow-gauge San Juan Extension.

Another problem unrelated to wars involved turnover in mill management. Charles A. Chase's son, Charles H. Chase, became the mill superintendent in 1945, but he left after only three years. Aldo Bonavida took his place at the mill.

The Turbulent Fifties (1953-1960)

William King, conducting a reconnaissance of the metal mining in the region for the Bureau of Mines in 1950, described the milling technology of the Shenandoah-Dives Mill that received its ore via tramway from its mine in Arrastra Gulch in simple detail,

> The ore is then (after fine store bin) passed through a Symons 4-foot short-head cone crusher and is delivered to a 6 by 8 foot Marcy grate mill … The Marcy mill discharges through a 6-mesh trunnion-trommel screen to a Dorr classifier in closed circuit. The classifier grounds are split, a variable amount being fed to a 6 by 6 foot Stearns-Roger overflow ball mill, and the balance as desired is returned to the Marcy Mill. The Stearns-Rogers mill also discharges through a 6-mesh trunnion-trommel screen, and the plus 6-mesh material is returned to the Dorr classifier that operates in conjunction with the Marcy mill. The overflow from the classifier, which serves both ball mills … furnishes the feed for the bulk flotation units
>
> The minus 6-mesh material from the trunnions-trommel screens … is passed over [Wilfley] tables, and the tailings are returned to the Dorr classifier … The bulk flotation circuit comprises

> six 66-inch cells used as roughers, followed by four 56-inch cells functioning as scavengers. The tails from the scavenger cells are wasted, and the froth concentrate is broken up and settled in two Dorr, 35-foot thickeners operating in series. The underflow, the thickened material, is reground in a 4 by 10-foot Stearns-Rogers tube mill operating in closed circuit with a 6-foot Esperanza-type classifier. The Esperanza-type classifier overflow furnishes the feed for the lead flotation circuit … comprises 12 flotation cells, and the product, a copper-lead concentrate is filtered.
>
> The tailings from the lead circuit are conditioned for 30 minutes and raised to a temperature of 70 degrees Fahrenheit … the zinc is activated by a solution of ammoniacal copper sulfate fed to the conditioner. The concentration is made by six flotation cells. The froth from these cells is pumped to the zinc filter, and the tails are returned to the bulk circuit.[58]

King included a table of the reagents, amounts used, and points of addition, noting that frothers were added during the grind stage, bulk rougher, and conditioner, and again in the zinc circuit. His description was one of a productive and profitable operation, but, unfortunately, it would not remain one much longer.

The outbreak of the Korean War in 1950 had renewed the military's demand to some extent, but a combination of events, economics, policy changes, and public perception of the industry set a rapid decline of the mining industry in Silverton, San Juan County, and the West in motion. At the Shenandoah-Dives Mining Company, the last concentrate—milled from custom ore—left the mill in April 1953, and the facility was mothballed. Shortly thereafter, a shakeup in company management that started with the firing of General Manager Charles A. Chase began the precipitous decline and eventual closure of the company.

The Standard Metals Era (1960-1985)

Although the mill reopened for a short while in 1958, declining market demand stalled any major changes in the mill until Standard Metals Corporation bought the operation in 1960. Over the next two decades, Standard Metals made several major additions to the mill, including constructing a crushing plant, a new sampling plant, and

[58] William H. King and Paul T.Allsman, "Reconnaissance of Metal Mining in the San Juan Region," U.S. Department of the Interior, Bureau of Mines, Information Circular 7554 (March 1950), 106-107.

raising the roof of the old flotation area for installation of an additional twenty flotation cells. Initially, only ten were put into operation in the zinc circuit. Later the other ten were incorporated into the flow.[59]

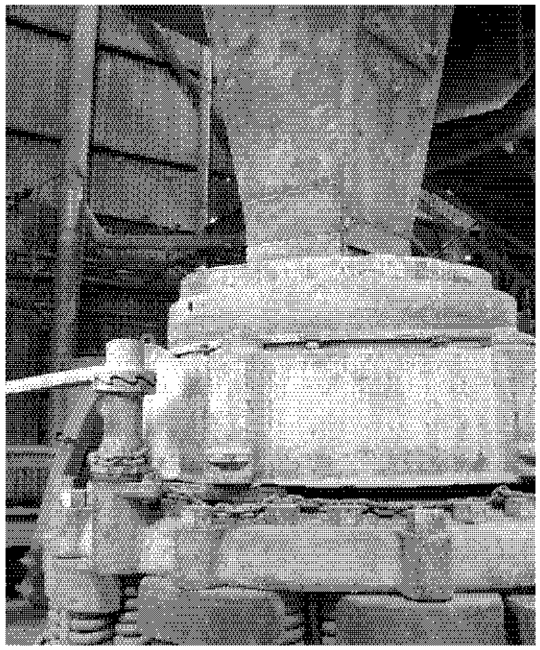

Figure 15. Symons shorthead cone crusher installed in the Crushing Plant. (Dana Lockett, HAER Architect)

Some ore arrived via the tramway from the Silver Lake operations (Mayflower mine portal connected to Silver Lake), but even more came in by truck from the Sunnyside Mine and American Tunnel diggings (lead and zinc ore). Therefore, it was necessary to build a new coarse ore bin, which required removal of the 1930s-era sampling plant and construction of a new ore bin and crushing plant on that site. At the same time, a Symons cone crusher was moved from the mine and added to the crushing circuit. The assay office was moved to the abandoned Animas Power sub-station, a short way down the road towards Silverton. Standard Metals also had a warehouse, timber shop, and truck scale at that site. These improvements were completed by 1962, and they resulted in a process outlined by the flow sheet in Figure 16.

[59] Allan Bird, "Report on the Mineral Properties of Standard Metals Corporation," 10 November 1979, Manard Ayler Mine Report Collection, Russell L. and Lyn Wood Mining History Archives.

By 1964, twenty-five men were employed at the mill. Approximately 900 tons of custom ore per day was arriving at the plant a year later. Then the Shenandoah-Dives Mine was closed and the tramway abandoned. During a year of particularly heavy snowfall, an avalanche took out tramway towers 3, 4, and 5. Being obsolete, the tramway was not repaired, but its remaining towers and components were left in place.

Environmental regulations in the 1960s prompted the company to improve the tailing ponds "in line with current stream and river pollution regulations and practices."[60] Improvements made in 1965 included a hydro-cyclone-type classifier to replace the wooden launders, sluices, and spigots.

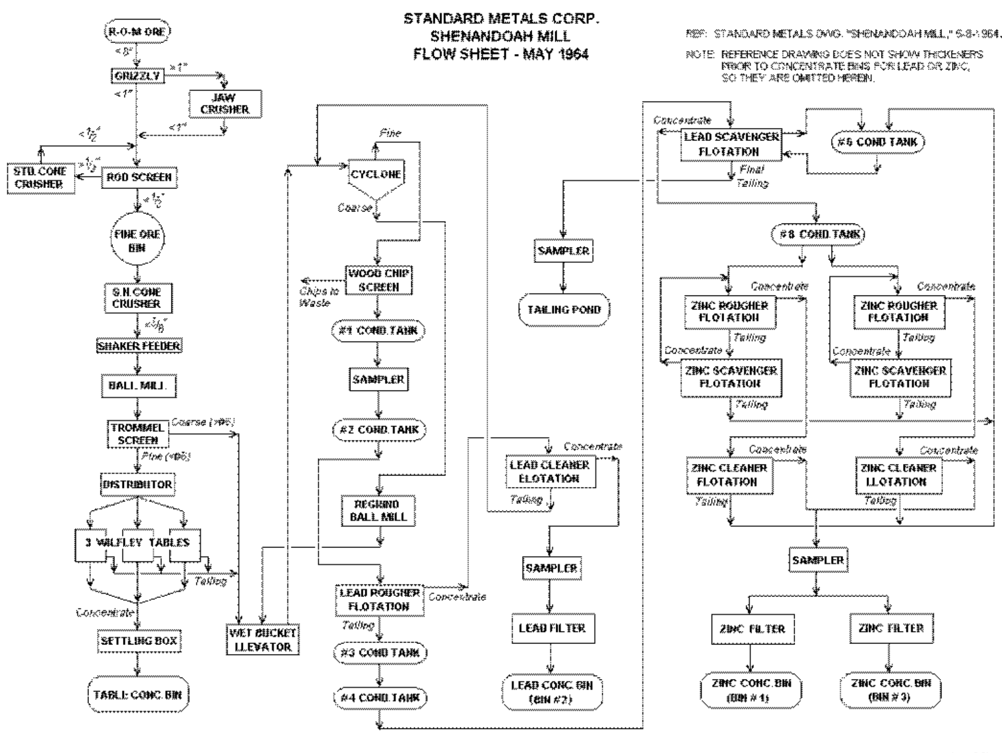

Figure 16. Shenandoah Mill 1964 flow sheet. This flow sheet is based on a Standard Metals Corp. flow sheet drawing dated May 8, 1964.

As gold prices climbed in early 1972, Standard Metals installed a gold circuit that included a jig concentrator, barrel amalgamator, and other equipment transferred from the

[60] Jones, "History of Mining and Milling Practices."

company's defunct Antler Mill in Arizona. Two gold circuits were ultimately installed: an amalgamation circuit for relatively high-grade ore and a cyanide strip circuit to recover additional gold from the low-grade amalgamation tailings. In addition, Mill Manager Allan Bird began construction of a building expansion to house additions to the fine-grind circuit. It was built at the northwest corner of the mill, on a level above the existing ball mills. To make room for it, one of the two wood-stave tanks located there had to be demolished. A used 1956 Dominion 8'x12' rod mill was added to the fine grind circuit in 1976, and the 6'x5' ball mill was placed back in operation. In the rod mill, ninety-two steel rods (each 11'-3" long by 3" in diameter, and weighing 500 pounds) totaling approximately 48 tons were charged into the rod mill for grinding. Water was first introduced into the ore at this stage. At this point, ground ore and water became slime, approximately 60 percent water and 40 percent solids.[61]

Figure 17. Dominion 8'x12' rod mill (L) and Denver spiral classifier (R) installed in 1976. (Dana Lockett, HAER Architect)

Figure 18 shows the flow sheet with these additions. The product from the rod mill flowed through a launder to a Denver spiral classifier for sorting. This consisted of a settling tank in the form of an inclined trough open at the upper end. The feed entered

[61] Manard Ayler, "Standard Metals Properties, San Juan County, Colorado, 1980," unpublished typescript, Russell L. and Lyn Wood Mining History Archives; Jones Outline; and Bird, "A Report on the Mineral

near the center via the launder and the slime overflowed at the closed end, while an auger "raked" settling sands uphill and out to the cyclone classifier. Here, classification of slime directed fine materials to flotation circuits and coarse materials to the No. 86 Marcy ball mill for regrinding along with the coarse material from the spiral classifier. With these improvements, the mill's capacity rose to 1,000 tons per day.

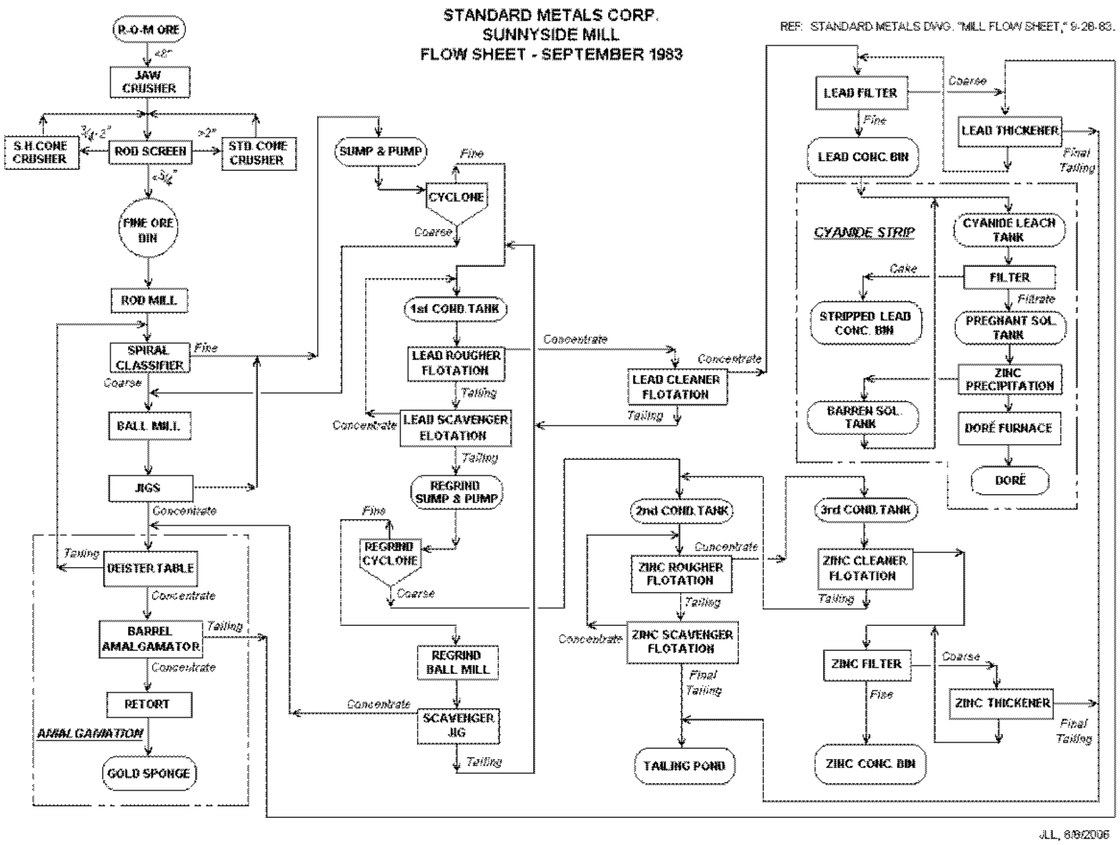

Figure 18. Sunnyside Mill 1983 flow sheet. This flow sheet is based on a Standard Metals Corp. flow sheet drawing dating from September 26, 1983.

In this configuration, the first metal separated from the ore was gold. Geologist Manard Ayler described the gold circuit from this period in a 1980 prospectus as including two units.[62] The first unit, or "hutch," was the amalgamation process. Fine sand from the ball mill went to a Denver duplex jig that fed a Diester Model 6

Properties of Standard Metals Corporation, 1979."
[62] Ayler, Standard Metals Properties, 1980.

concentrator table.[63] Similar to a Wilfley table, the Diester table mechanically separated the heavier and lighter ore sands. As the watery flow passed over the vibrating, slightly tilted table at the feed side, the heavier, higher-grade concentrates—those containing the most gold—settled against the riffles at the concentrate side. From the concentrate side of the table, these heavy concentrates rode off the table edge into a settling tank, while the lighter waste material floated off with the water to be recycled through the spiral classifier. The concentrate then went to a 2'x4' barrel amalgamator and retort for processing into gold sponges. The amalgamation process used mercury, which was added to the slurry in the barrel amalgamator, to "wet" and surround the gold, forming a solid mixture called amalgam that separated from the gangue. Operators collected the amalgam and loaded it into a Telluride Iron Works 2.5'x4' retort to flash off the mercury, which vaporized at a lower temperature than gold. Most of the mercury vapor was condensed for reuse, though some undoubtedly escaped into the atmosphere. The melted gold in the retort was poured into molds to form gold sponges that went to a gold smelter for further refinement.

Meanwhile, the gangue from the amalgamator went to the lead thickener and, finally, the second hutch, a cyanide strip circuit. Here, a dilute sodium cyanide solution leached the gold out as gold cyanide. Residual lead was then filtered out, and zinc was added to separate the gold from the cyanide and generate a precipitate of zinc and gold. After the zinc was removed with sulphuric acid, the resulting gold sludge was melted in a furnace and cast into bars known as doré. The stripped lead became part of the mill's base metal production, but it still contained a significant amount of gold, along with silver, that could be separated later in smelting. According to Ayler, this second hutch produced "about 12-25 oz. gold per ton" of ore.

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[63] This table replaced earlier shaking tables known as Wilfley tables. Both were slightly inclined tables with riffle cleats that separated light from heavy particles in the slime pulp. See "Wilfley Concentrator," *Catalog No. 22* (Denver, Colorado: Mine and Smelter Supply Company, n.d.), 206-207; and *The Diester Concentrator*, (Fort Wayne, Indiana: Diester Concentrator Company, n.d.).

Figure 19. Gold recovery equipment installed in 1982 included a Diester Model 6 concentrating (shaking) table. As a thin film of water passed over the slightly sloped, vibrating table, the heavy gold particles tended to collect on the rifling and migrate to the lower right corner. (Dana Lockett, HAER Architect)

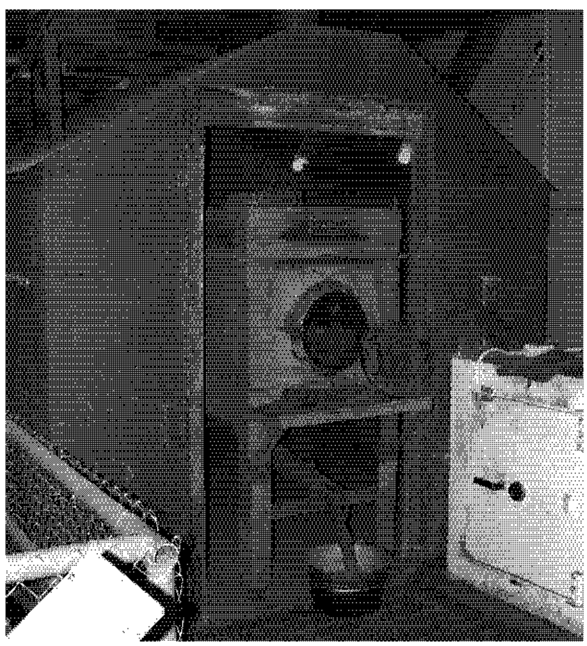

Figure 20. Telluride Iron Works retort used to separate mercury from gold. The hood collected and condensed most of the mercury vapor for reuse. (Dana Lockett, HAER Architect)

While gold became an important product during the 1970s, the mill's flotation lines continued to churn out lead and zinc, but with some differences from the earlier process. The addition of the gold-recovery equipment required a wetter slime pulp through and after the ball mill than had previously been used. Thus, a slurry pump replaced the old wet bucket elevator, which was removed. Since the bottom of the elevator shaft happened to be at the only entrance to the gold-processing area, the company installed a guardroom to enhance security. (With this guardroom addition and a modification to the floor above that obliterated the opening for the wet bucket elevator, virtually no evidence of it survives to the present day.) A second sump pump and cyclone separator were added to the regrind circuit about this time as well.

Just as the mill's future looked brighter than it had in two decades, a series of misfortunes hit, beginning with a failure of Tailing Pond Number 1 in 1974 that released waste material into the Animas River and cost the company a significant fine. Tailing Pond Number 1 was repaired to prevent future discharges and closed. New tailing ponds were added to the site.

On June 7, 1978, Lake Emma broke through into the mine. During the six-month shutdown to de-water the mine, Mill Manager Bird took the opportunity to make improvements to the electrical control equipment, replace the concrete Fagergen cells with Gallagher Cells, and add lead cells.[64]

At this time, the mill processed three products: lead, zinc and gold. The company's 1979 annual report noted that the "Tonnage of ore milled increased 24 per cent due to completion of additions to the mill in third quarter of 1976." The mill had processed 244,860 tons in 1976.[65]

Manard Ayler's 1980 prospectus for potential investors in the Standard Metals Corporation effectively outlined the improvements made during the previous decade. The company had replaced obsolescent flotation circuits, added to the gold amalgamation circuit, removed the wet-bucket elevator, installed a guardroom at the bottom of the shaft, and brought wiring and equipment up to OSHA standards, substantial improvements in

[64] Ayler, "Standard Metals Properties, 1980," and Jones Outline.
[65] "Shenandoah-Dives Operations, Standard Metals Corporation, 1979," unpublished typescript housed in Russell L. and Lyn Wood Mining History Archives.

anybody's estimation. Of the three concentrates produced—lead, zinc, and gold—the lead concentrate contained most of the silver and 40 percent of the gold, while the zinc concentrate held only minor amounts of silver and gold. The gold amalgamation circuit concentrated 45 percent of the gold.[66]

The company continued to issue news releases reporting, "near record earnings" and "net smelter value in fourth quarter reaches approximately seven million dollars at full operation (now 1,000 tpd)" in 1981.[67] Despite these optimistic reports, the company was actually in serious financial condition. Non-mining subsidiary losses caused Standard Metals Corporation to file for bankruptcy protection in 1984. When conditions failed to improve, the company was finally forced to close the plant in April 1985. That November, Standard Metals sold the Silverton operations to Sunnyside Gold Corporation, a subsidiary of the Canadian firm Echo Bay Mines Limited.

The Sunnyside Gold Era (1985-1991)

Sunnyside Gold quickly reconfigured the amalgamation gold-recovery circuit by inserting a jig between the spiral classifier and ball mill and adding a Hazen-Quinn strake just ahead of the Deister table.[68] The first modification allowed material that had been adequately ground in the rod mill to by-pass the ball mill, leaving it to more efficiently grind only the material that actually needed additional grinding. By removing the larger gold particles, the strake passed more consistent material to the Diester table, increasing its productivity.

Amalgamation was very sensitive to the cleanliness of the mercury used. The presence of oil, grease, clay, manganese and iron sulfates, or base metal and iron sulfides could result in "sickening" (loss of ability to "wet" and surround the gold) or "flouring" (formation of very small globules that easily sicken) of the mercury that seriously diminished recovery. Adding an alkali such as hydrated lime or lead nitrate at the

[66] Ayler, "Standard Metals Properties," 1980, and "Letter to the Shareholders," January 7, 1980, unpublished typescript, Russell L. and Lyn Woods Mining History Archives.
[67] News releases for January 26, 1981, and March 16, 1981, unpublished typescripts, Russell L. and Lyn Woods Mining History Archives.
[68] A strake was a wide launder or sluice set at a slope and covered with a blanket or corduroy for catching coarse gold. See Thrush, *Dictionary of Mining,* 1085.

grinding stage usually prevented mercury sickening. The noticeable change at the mill from this was the erection of a new lime storage building behind the main mill building.

With these alterations improving the amalgamation yield, Sunnyside decided to abandon the cyanide strip circuit and its attendant hazards. Yet another modification sought to further diversify the mill's products by adding equipment to separate copper from the lead so that it could be shipped separately to copper smelters. This flow sheet is shown in Figure 21. Along with improving the process, the company also made some effort to improve conditions for mill employees, including the addition of a dry-room trailer for employees' clothes lockers adjacent to the mill's southwest corner.

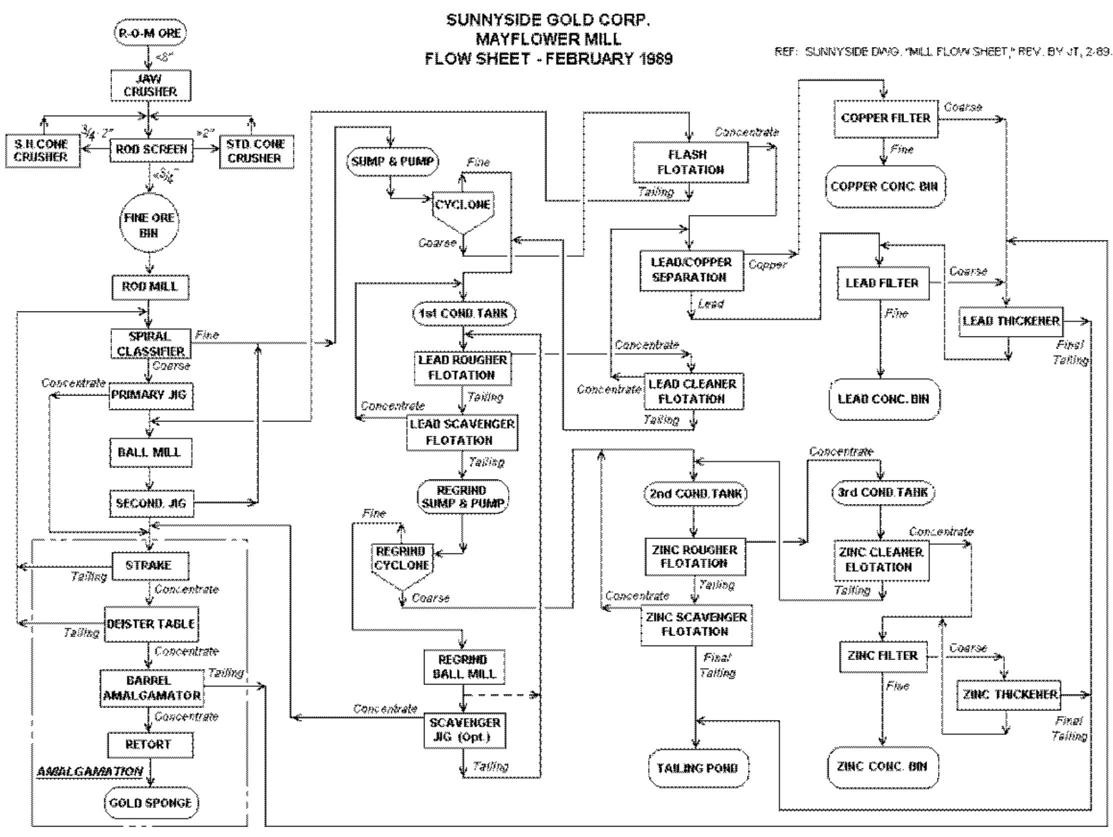

Figure 21. Mayflower Mill 1989 flow sheet. This flow sheet is based on a Sunnyside Gold Corp. flow sheet dated February 1989.

In spite of the improvements, profits from the operation remained slim. In an effort to pull out of the Silverton operation, Sunnyside Gold twice initiated joint ventures with other companies. Since these partners acquired considerable influence over the operation with their investments, it is not surprising that they had an effect on mill management. Although the employees continued to actually work for Sunnyside Gold, the situation must have been difficult for the mill superintendent. Over the six years that Sunnyside owned the Shenandoah-Dives operation, it employed three different mill superintendents, William Banning, Barney Darnton, and Joe Todeschi. Whether lack of success caused the frequent turnover, or vice versa, is hard to determine, but neither joint venture was successful. By 1990 Sunnyside Gold Corporation again found itself the sole owner of the property.

In June 1991, Sunnyside announced it was closing the mine and mill due to declining zinc prices and the lack of gold reserves remaining in the mine. The mill processed its final concentrates in mid-August. The next year was spent cleaning up residual gold and concentrates and surface reclamation of the tailing ponds and mine.[69]

CHAPTER 7: CONCLUSION

The Shenandoah-Dives Mill is an excellent example of early twentieth-century flotation mills that were once found throughout the hard-rock mining districts of the American West. Charles A. Chase, founding general manager of the Shenandoah-Dives Mining Company, incorporated the newest innovations available in 1929 into this flotation mill. Working with some of the best engineers, metallurgists, and mill men in the West, Chase created a plant that would remain viable for over two decades with only minimum improvements to replace worn equipment. Chase's era ended in 1953, but subsequent companies continued to modernize and operate the mill on and off until it processed its last ore in 1991 and officially closed after clean up a year later. At that time, the mill and associated property were donated to the San Juan County Historical Society to be operated as an interpretative center.

With the mill's closure, Silverton's population rapidly dropped—to only 531 residents according to the 2000 census. Today, much as in other former mining towns in the Rocky Mountain West, the economy of Silverton and San Juan County is based on

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[69] Jones, Outline.

local government activities and tourism. Thus, as a museum, the Shenandoah-Dives Mill continues to support the local economy.

With its machinery and fixtures intact and in situ, the Shenandoah-Dives Mill well represents and illustrates the technology that made modern mining and metal recovery practical throughout the western portion of the United States and elsewhere. Although this mill now serves as a museum, its closure was due more to the surrounding mines playing out than to obsolescence of the mill itself. Flotation remains the primary milling process at other locations where mines continue to yield profitable quantities of precious, semi-precious, and base metals. At Shenandoah-Dives, all of the necessary equipment is here to see and study at close range.

But to examine this mill and study the lives of the men who toiled here to make the earth yield some of its treasure is to gain much more than merely a sense of how one basic industry functioned. The spirit of a particular breed of pioneering people who could, and did, challenge all that nature and a wild land could offer still haunts this place. Walking these halls, one can sense that bold, inventive spirit and gain a deeper understanding of a distinctly confident attitude that continues to flavor the American experience.

Figure 22. This aerial view looking northwest shows the Shenandoah-Dives Mill complex as it appeared in 2005. (Courtesy of San Juan County Historical Society)

APPENDIX A: CHEMICALS AND REAGENTS

This list includes the chemicals and reagents used at the Shenandoah-Dives Mill during its later years of operation. Most are generic compounds, identified by their chemical formulas, that were in use throughout most, or all, of the mill's service life, depending on the process and target metals at the time. Those identified by name or number are proprietary products developed by commercial chemical suppliers to accomplish or enhance specific processes or reactions.

NaCn	Sodium Cyanide. Solid pellets from Dow Chemical Company. Stage feeding of a 5 percent solution in the grinding and lead flotation circuits. Functions as a depressant for pyrite (iron sulfide) and sphalerite (zinc blende) in lead flotation.
$ZnSO_4$	Zinc Sulfate. Solid beads from various suppliers. Stage feeding of a 10 percent solution in the grinding and lead flotation circuits. Functions as a depressant for sphalerite in lead flotation.
Na_2SO_3	Sodium Sulfite. Solid powder from various suppliers. Stage feeding of a 10 percent solution in the grinding and lead flotation circuits. Functions as a depressant for pyrite and sphalerite in lead flotation.
404	Liquid promoter (mineral collector) from American Cyanamid Company. Stage feeding of a 10 percent solution in the grinding and lead flotation circuits. Functions as the primary collector for gold, silver, lead, and copper.
325	Sodium Ethyl Xanthate, Salt of Xanthic, or Dithiocarbonic Acid. Solid pellets from American Cyanamid Company. Stage feeding of a 10 percent solution to lead and zinc flotation. Functions as the secondary collector in lead flotation, or as a primary collector in zinc flotation.
350	Potassium Amyl Xanthate. Solid pellets from American Cyanamid Company. Stage feeding of a 10 percent solution to zinc flotation, mixed directly with 325. Functions as the stronger of the two zinc collectors.
250	Dowfroth Frother. Liquid Polypropylene Glycol Methyl Ether from Dow Chemical Company. Stage feeding of a 25 percent solution to lead

	and zinc flotation. Functions to prolong the life of mineral laden bubbles, thus enhancing recovery.
$Ca(OH)_2$	Lime, or Hydrated Calcium Hydroxide. Solid powder from various suppliers. Stage feeding directly to the roughing and cleaning conditioners of zinc flotation. Functions as a pyrite depressant in zinc flotation, also to achieve an alkaline pH for tailings water treatment. Can also consume sulphide ions to inhibit mercury sickening.
$CuSO_4$	Copper Sulfate. Solid crystal from various suppliers. Added as a near saturated solution at zinc conditioning. Functions as an activating agent to aid in collection of sphalerite.
Tergitol	Nonionic surfactant from Union Carbide Corporation. Liquid added as a 10 percent solution to final flotation concentrates feeding the vacuum filters.
65% $Ca(OCl_2)$ 33% chlorine	Calcium Hypochlorite. Solid granules or pellets from various suppliers. Added directly or in solution to the tailings pulp and the thickener overflow water. Functions as an oxidizing agent for treatment of cyanide in tailings discharge.
7852	Ionic coagulant. Liquid from Nalco Chemical Company. Added full strength to the thickener feeds. Functions as a source of positive charge for the mineral particle surfaces.
7872	Anionic flocculent. Liquid from Nalco Chemical Company. Added as a 1 percent solution to the lead thickener feed. Functions as a bridging mechanism to bring mineral particles together so they settle faster.
NaOH	Sodium Hydroxide. Solid beads from various suppliers. Added directly to the grinding phase of amalgamation. Functions as a strong alkali to dissolve or decompose organic contaminants in the gravity concentrate.
$C_6H_{11}O_7Na$	Sodium Gluconate. Food additive, solid powder from various suppliers. Added directly to the grinding phase of amalgamation. Functions as a cleaning agent to help remove oxide stains from the gold particle surfaces.
$Pb(NO_3)_2$	Lead Nitrate. Solid crystals or powder from various suppliers. Added directly to the grinding phase of amalgamation. Functions as a source of positive ions to consume sulfide ions and thus prevent sickening of mercury.

MIBC	Methyl lsobutyl Carbinol (or Methyl Amyl Alcohol). Liquid from various suppliers. Same function as Dowfroth 250 frother, currently being mixed with 250 and water for stage feeding throughout the flotation.
NH_4Cl	Ammonium Chloride. Solid powder from various suppliers. Added directly to the grinding phase of amalgamation. Functions the same as sodium gluconate in removing stains from gold particles thus enhancing contact with mercury.
Hg	Liquid Mercury. Added directly to the slow grinding phase of amalgamation (which follows the grinding phase with chemicals). Recovers gold by forming a solid solution (amalgam) with it. The combination is then recovered from the pulp using elutriation.
$Na_2Cr_2O_7$	Sodium Dichromate. Solid granules or powder from various suppliers. Added as a 10 percent solution to the conditioning stage prior to lead/copper separation. Functions as a depressant for the lead mineral galena.
Na_2SH H_2O	Sodium Hydrosulfide. Solid flakes from various suppliers. Added as a 20 percent solution to the tailings pulp. Functions as a reducing agent for Cr +6 ions (from lead/copper separation), changing them to Cr+3 so that they will precipitate from solution with other heavy metal ions, as mandated by the water quality requirements at the tailings pond.

APPENDIX B: EQUIPMENT AND PROCESS CHANGE CHRONOLOGY

This chronology of major events in the life of the Shenandoah-Dives Mill was primarily drawn from a chronology developed by William R. Jones in 1996.

5-1929	Prospectus for Shenandoah-Dives Mining Co. issued.
6-1929	Shenandoah-Dives Mining Co. incorporated as a Colorado company. Mill construction began.
10-1929	Original mill construction substantially completed.
1-1930	Telsmith 16A gyratory (primary) and Symons 4' standard cone (secondary) crushers at mine began operation. Tram began operation.
2-1930	Mill began operation as Shenandoah-Dives Mill.
1931	Symons crusher at mine modified to improve discharge from 3/4" to 3/8".
1931	4' x 10' Stearns-Roger regrind ball mill installed in flotation circuit.
5-1932	Symons short-head cone crusher installed ahead of (physically beside) Marcy 8' x 6' ball mill, in Mill Building.
1936	Custom ore bins and Crushing and Sampling Plant began operation.
1937	Process modified, probably using Denver No. 18 flotation cells, to separate lead-copper and zinc from bulk flotation product.
1937	Stearns-Roger 6' x 5' ball mill installed in an addition to Mill Building.
1938	Process further modified to separate lead from copper, so lead, copper, and zinc concentrates could be separately shipped to product-specific smelters.
3-1938	Snow slide destroyed tram towers 1, 2, 3, 4, and 5. Towers were rebuilt and an avalanche deflector built above tower 2.
1943	Fagergen concrete flotation cells installed, probably in lead rougher circuit.
1944	Denver Sub-A flotation cells installed in lead cleaner circuit.
4-1953	Mill closed.

1957 Marcy-Shenandoah Corp. created by the merger of Shenandoah-Dives Mining Co. and Marcy Exploration Corp., a uranium mining company based in Durango, Colorado.

1957 Universal Pictures filmed portions of movie *Night Passage* at mill.

1959 One-half interest in mine and mill sold to Standard Uranium Corp. of Moab, Utah.

1960 Standard Uranium Corp. changed its name to Standard Metals Corp. and purchased remaining interest in mine and mill.

7-1960 Mill reopened as Shenandoah Mill.

1-1961 Mill put on stand-by status.

1961 Ten flotation cells installed for zinc concentrate, with a portion of flotation room roof raised to accommodate them. (Ten more cells were intended for manganese separation, but never installed.) 1936 Crushing and Sampling Plant demolished, and new Crushing Plant built. Discharge end of tram rail modified (possibly demolished) at this time. Symons standard 4' cone crusher moved from mine to Crushing Plant. New coarse ore bin replaced 1936 custom ore bins, and mill likely started receiving all ore via trucks. 1936 custom ore bins abandoned in place (except for one used to store ball mill balls). Assay Office moved from Mill Office Building to Animas Power Substation Building, and new truck scale installed.

8-1962 Mill reopened, still as Shenandoah Mill.

1963 Last possible use of tram, assuming it was serviceable after 1961.

1964 Symons short-head cone crusher moved from Mill Building to Crushing Plant.

ca. 1965 Snow slide destroyed tram towers 3, 4, and 5. They were not rebuilt.

1971 Bankrupt mine and mill closed for about 6 months, then reopened.

1972 Jig concentrator and barrel amalgamator installed to recover high-grade gold. Wet bucket elevator likely removed at this time.

1973 Second jig concentrator installed.

1974 Zinc flotation cell replacement begun with used cells from Antlers, AZ, mill.

1976	Used Dominion 8’ x 12’ rod mill and spiral classifier installed between fine ore bin and Marcy ball mill in an addition to Mill Building.
1977	Replacement zinc flotation cell installation completed.
6-1978	Mill closed.
1978-80	Extensive renovations done, including new electrical equipment (and new electrical room at Crushing Plant) and installation of Galigher Agitair flotation cells to replace 1943 Fagergen cells.
1-1980	Mill reopened as Sunnyside Mill.
1979	Reinforced Earth Co. retaining wall installed on north side of Crushing Plant.
1982	Assay Office moved back to Mill Office Building and guardroom built in former wet bucket elevator shaft inside Mill Building. Deister table installed. Lime Storage Building built.
4-1985	Mill closed.
11-1985	Mine and mill sold to Sunnyside Gold Corp., a subsidiary of Echo Bay Mining Co. of Edmonton, Canada.
1986	Mill reopened as Mayflower Mill.
8-1991	Mill production ends.
1992	Mill permanently closed.
1993	Agreement in principle reached for Sunnyside Gold Corp. to donate mill to San Juan County Historical Society.
1995	Surface reclamation of tailing ponds substantially completed.
1997	San Juan County Historical Society opened mill museum.
2-2000	Mill designated a National Historic Landmark.

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