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Win Some, Lose Some
The Evolution of Milling Practice on the Comstock Lode

Eugene J. Michal

Introduction

Many references in the literature mention the fact that the nineteenth–century mills on the Comstock Lode were notoriously inefficient in recovering gold and silver from the ore. Precious metal recoveries by the Washoe Pan Process, the preferred treatment method at that time, have been described as in the range of 65 to 70 percent, and in some instances even lower. With the benefit of hindsight, Grant Smith concluded that the initial pan treatments lost more than $100 million in gold and silver, while recovering about $300 million, but that later reprocessing of tailings recouped $23 million of those losses.[1]

Loss of precious metals in milling was a problem encountered in the earliest mills, and, although many alternative ore treatment methods were tried, substantial losses persisted throughout the entire life of milling operations. This led to condemnation and vilification of the mine owners and operators. The mood was most emphatically expressed at that time by Eliot Lord, who said, "In the competition to reduce as many tons of ore per day as possible the mill owner cared little for the constant waste of metal in the slimes and tailings—thus the Carson River flowed like the Pactolus[2] over precious sand, and its bed is lined with ores of varying thickness." Lord also reminded his readers that "A century before, a Spaniard had written 'A class of men so necessary to the mining body as the amalgamators should be well-educated and should be subject to an examination, as in the Royal Mints,' but, added Lord, "the proposed requirement of evidence of competence from mill men would have abridged the privilege of American Citizens to waste the mineral resources of the public lands without hindrance."[3]

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The loss of precious metals was not disputed, but it was not the only error of these early operations. Lord's criticism has an echo today in the declaration of fifty miles or more of the Carson River as a Superfund Site, primarily as a result of contamination by mercury from these early operations, with little hope of its reclamation in the foreseeable future.[4]

The earliest mill operators tried to adapt California stamp-mill amalgamation to the Comstock ores, but they faced an unfamiliar and unforeseen complication. Most of the silver in the ore was present as a sulfide and could not be recovered by simple amalgamation. Thus began a search for a better treatment method. It led to the trial of the Mexican Patio Process in 1860, the European Freiberg Process in the years 1861 to 1863, and finally to the development, by 1866, of the Washoe Pan Process. This article will describe the steps in this search, and explain why the final choice became the Washoe pan. However, even the Washoe pan gave only about 70 percent recovery of the silver, and the losses were what led to Lord's scorn for those who "waste the mineral resources of the public lands."

THE EARLY DISCOVERIES

Comstock gold was first found in 1850 in a gulch tributary to the Carson River near the present town of Dayton. For the next eight years, the gulch, which became known as Gold Canyon, was prospected intermittently over a length of several miles, with mediocre results. In January of 1859, a party including "Sandy" Bowers, Joseph Plato, Henry Comstock, James Rogers, and William Knight followed the gold values up Gold Canyon almost to its top. There they located a claim fifty feet wide and four hundred feet long across the gulch, giving ten feet of width to each man. The results in washing for gold seemed promising, but James Rogers had become indebted to Eilley Orrum, the recently divorced proprietress of the local boarding house; he could not pay his bill, and signed his ten feet of the claim over to Eilley before departing for California.

The mine prospered, for as it increased in depth the values became even richer. The formation gradually transformed from gravel to a decomposed rock the miners called the Old Red Ledge, which they dug out of the hillside, crushed with hammers, and washed for gold. The new mining area was christened Gold Hill. They had dug into the top of what would later be known as the Gold Hill Bonanza.

At almost the same time, another pair of prospectors, Peter O'Riley and Patrick McLaughlin, working at the head of Six Mile Canyon, about a mile north of Gold Hill, were having a similar experience with rock formations on their Ophir claim. They had found gold mineralization, and the values improved as they dug deeper, but the rock became harder and a heavy blue mineral appeared, which clogged their sluice boxes in the washing process. They discarded the blue mineral, and, to solve the problem of crushing their ore, gave two entrepreneurs, John D. Winters and J. A. Osborne, a one-third interest in their claim in return for building two arrastras and supplying the horses to turn them.

As the shafts of Bowers and fellow miner James Fennimore deepened and the rock increased in hardness, they, too, adopted the arrastra grinding process, and the method spread to other prospects in the area. In the spring of 1859, Henry DeGroot reported that there were "half a dozen arrastras in operation at Gold Hill".[5]

Arrastra Amalgamation

Arrastra amalgamation was a procedure in which large stones were dragged around over partially crushed ore in a circular stone-lined pit—the arrastra—by horses or mules to grind it to a fine powder to which quicksilver is added. Grinding rock in the arrastra in the presence of mercury liberated and collected the gold as an amalgam that could be washed clean in a stream of water. However, washing it clean was complicated by a troublesome accumulation of heavy blue sands. A visitor to the Ophir diggings took some of the " heavy blue stuff" back to California, had it assayed, and found it rich in silver. Judge James Walsh and Joseph Woodworth, his partner, heard of the assay result and headed for the Carson Valley, where, in July of 1859, they acquired an interest in the Ophir, and made known the news of the values in silver.[6] Soon, by hand sorting, the Ophir claim had yielded thirty-eight tons of the blue ore, which, carried to San Francisco on the backs of mules, is said to have yielded $112,000.[7]

Almost as quickly as the discovery of silver on the Ophir was announced in mid 1859, Sandy Bowers became aware of the same blue mineral in his mine. It was called silver sulfurets. Also hand sorting the blue mineral, Bowers then sent a shipment of one ton to San Francisco for smelting. It yielded $2,200.[8]

While sending such rich ore to San Francisco was profitable, it was apparent that the shipping cost, which ran as much as $600 per ton, was too high to justify for lower-grade ores, of which there now appeared to be an abundance. Since arrastra amalgamation did not adequately recover the silver values, it was clear that a better treatment method was required.

The Patio Yards

Gabriel Maldonado and his brothers, Mexicans of Spanish descent and early mine owners, had knowledge of the Patio Process for silver recovery used in Mexico and decided to apply it to treatment of Comstock ore. The process

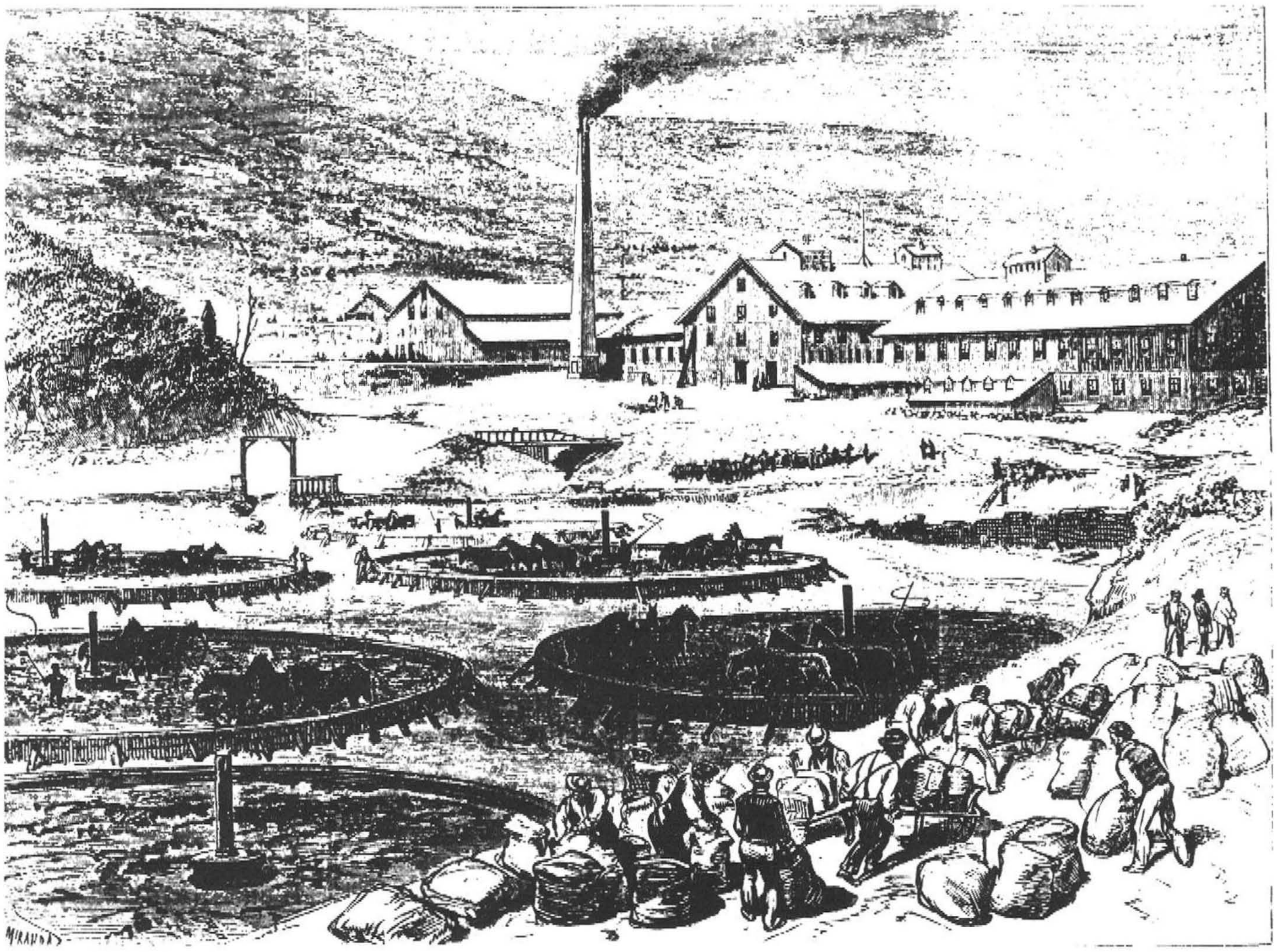


Figure 1. The arrangement of a patio with treading horses, the Gould and Curry Mill, Virginia City, Nevada that utilized the Washoe Pan Process, successor to the Patio Process. *(Camp Nevada Monograph No. 8. Used with permission)*

consisted of mixing the moist, crushed ore with salt, copper sulfate (bluestone), and mercury on a flat surface in open air and using mule power to turn it over repeatedly until the mercury had collected the silver. Figure 1 shows the arrangement of a patio with the treading horses. According to DeGroot, the Maldonados had, "by the spring of 1860, erected extensive Patio yards at Virginia City, with many arrastras." DeGroot continued, "These were the only works ever erected in Washoe wherein this plan of ore reduction was practiced on a large scale."[9] DeGroot later reported that by the end of 1861 there were forty or fifty arrastras and several patio yards in the district. However, it was noted that " when sulfurets were present in the ore this type of mill became wholly inadequate."[10] After a year or so, the patio yards were being abandoned because of poor recovery of silver.

The failure of the patio yards can be explained by examining the chemistry of the process. On the Mexican patios, silver sulfide, in the presence of copper sulfate, reacted with atmospheric oxygen and was decomposed, opening it up to amalgamation with mercury. This was a very slow process, required large areas where the ore could be spread out, aerated, kept moist, and mixed; and the chemical action was aided by the warm temperatures of Mexico. The cool, dry climate of Virginia City sounded the death knell for the chemical reactions on the patio. The chemistry of silver recovery by the Patio Process is described in detail in my article"The Chemistry of the Patio Process," which also appears in this issue. It explains how some, but not all, of the reactions in that process were finally used in the Washoe Pan Process.

Stamp Mill Amalgamation

Dr. E. B. Harris, a California dentist with gold-mining experience, and Almarin Paul, a California gold-mill operator, had heard of the rich discoveries on the Comstock and set out in 1859, independently, for Virginia City. Being familiar with the stamp milling of gold ores, both believed that stamp milling would be more economical than arrastra milling. Both planned to use mercury amalgamation after the stamp milling to recover the gold and silver, but neither realized the complications they would face in the recovery of silver.

Dr. Harris arrived in the Carson Valley at the time the Bowerses' mine was beginning to prosper from gold recovered by arrastra milling. There he proposed to the Bowerses (Sandy Bowers and Eilley Orrum had married by that time) that they join with him in erecting a stamp mill, using California milling technology. No agreement was ever reached with the Bowerses, but Harris secured financing elsewhere, erected a nine-stamp mill, and milled ore from the Bowerses' mine on contract, recovering values on amalgamation plates.

The gold produced by the Bowerses' mine was actually electrum, a natural alloy of gold and silver, and was reportedly worth "only $10 to $14 per ounce." As pure gold was worth $20 per ounce, the lesser value was due to its dilution with silver, "and as the mine increased in depth [the value] fell, owing to an increase in silver."[11] Wells Drury reported that the mine produced $18,000 per week for several years, aggregating $4 million, making the Bowerses the first millionaires on the Comstock.[12] Smith puts the production of the Bowers mine at $1.2 million, and the Boweres' profit at no more than $500,000.[13] Whatever the amount, it financed the Bowerses' legendary trip to Europe where Eilley's plans to meet Queen Victoria went awry—the Queen did not meet with divorced women.[14] However, the mine did pay for the elegant furniture that Eilley purchased in Europe for the Bowers Mansion in Washoe Valley.

When Almarin Paul arrived on the Comstock in 1859 believing, like Harris, that stamp milling would be more economical than arrastra grinding, he further thought that the ores could be amalgamated in steel grinding pans as was the case for gold ores in California. He took samples of ore from the upper levels of the Mexican and Ophir properties to his California mill and confirmed that he could recover the gold. Convincing several of his friends that they could make a profit by milling ore for others (custom milling), he pulled them together as the Washoe Gold and Silver Mining Company and, with a contract in hand to mill nine thousand tons of ore, erected a mill at Devil's Gate in Gold Canyon. The Harris mill and the Paul mill began operating within a few hours of each other in August of 1860.

The first two tests in the Paul mill yielded a gold bullion (electrum) similar to that from the Harris mill, with a value of between $12 and $14 per ounce, and were considered a success.[15] Although the value of the electrum recovered from the upper part of the ore body was primarily in gold, the bonanza ores discovered later were to have values primarily in silver, and the silver would occur predominantly as sulfide. Had Paul treated this latter type of ore in his mill, it would not have been considered such a success, as the silver values would have been lost. As time went on, he recognized the growing problem of losses of silver. He later wrote: "In 1860 and 1861 none of us knew anything about milling silver ores. We talked about the Patio, the Freiberg, and the Barrel [Processes]."[16]

As mills proliferated and the shafts deepened, silver recoveries from grinding and amalgamation became poorer and poorer, and a method for recovering the silver was needed. Such a method—the Freiberg Process—had been in use in Europe for many years.

THE FREIBERG MILLS

The Freiberg Process consisted of roasting the ore with common salt (sodium chloride) in a furnace in the presence of air to convert the silver sulfide to silver chloride. The silver in the silver chloride could then be recovered by mercury amalgamation in a rotating barrel. It was a logical thought to bring this process to the Comstock, and by 1861 three groups of investors were in a race to build Freiberg mills.

The Ophir Mill, built in Washoe Valley and put into operation in 1861, was probably the most elaborate of the Freiberg mills. It cost in excess of half a million dollars and included building a road down the Ophir grade into Washoe Valley and across the Washoe Lake on a bridge built on piles. The results of this massive plan were disappointing. Milling costs exceeded the values recovered, and, with losses of about one third of the silver, it was, in the words of Smith, "more or less a failure from the first."[17] Before long, in a desperate attempt to improve recoveries, a mill using the Washoe Pan Process was added, and in a still further attempt, patio yards were added. The mill was in operation barely three years when the higher-grade ore ran out and the mill was shut down.

The Mexican Mill, or Silver State Mill, was the brainchild of the Maldonado brothers, who had been unsuccessful with their patio yards in Virginia City, but who still had ore available from their Mexican claim. They appealed to Alsop and Company of San Francisco, smelters and refiners, and were successful in borrowing $170,000 to build a Freiberg Process mill in the Carson Valley.

That venture, too, had a sad ending, as they could not supply enough high-grade ore to operate the mill profitably, and it closed in 1862. The Alsop firm repossessed the mill, but it burned down in 1863.[18]

The Gould and Curry built a "monumental" Freiberg mill in Six Mile Canyon and put it into operation in 1863. This mill was also considered a failure. Precious-metal losses in the tailings were said to be 40 percent, and values recovered could not match operating costs. During this period the company shipped fifty tons of the richer sulfuret ore to Wales for treatment, and the returns averaged $1,800 per ton. In 1864, the mill was rebuilt at great expense to use the Washoe Pan Process, and a recovery of 65 percent of the values was achieved with much lower operating costs. But by 1865, the high-grade ores had played out and the mill was shut down.[19]

The Freiberg mills failed for two different reasons. The first reason was that the process had been developed for treating concentrates rich in silver, not the large volume of lower-grade ores the Comstock was producing. The costs of fuel for the furnaces and of hand rabbling of the furnace charge were excessive, and the mill was not economically viable. While most of the Freiberg mills were shut down by what was described as "running out of ore," what they really meant was "running out of high-grade ore."

The second reason was that there was a loss of gold in chlorination roasting. Smith[20] wrote that "The Freiberg Process was successful in saving the silver, but lost part of the gold. The Washoe process saved the gold, but lost part of the silver." Charles Stetefeldt had encountered loss of gold from Comstock ore in 1869, but it was not until 1885 that he established the reason for the loss.[21] The essence of the problem is that salt in a furnace in the presence of sulfur dioxide generates chlorine gas, and this gas converts the gold to a volatile chloride, which escapes up the smokestack and is lost.[22] This was a problem for the Freiberg furnaces as well as for the Stetefeldt furnace. Neither was applicable to ores containing gold, even though chlorination would undoubtedly have improved silver recovery from the Comstock ores.

Development of the Washoe Pan Process

Almarin Paul, who was one of the first to introduce the stamp mill and the iron grinding-and-amalgamation pan to the Comstock Lode, made a study of the Ophir and Gould and Curry mills on the Comstock Lode and described them in a series of articles in the *San Francisco Call-Bulletin* in 1862 and 1863.[23] It was obvious to Paul that the Freiberg Process was too expensive to be used on any ores valued at less than $50 per ton. This gave him a renewed impetus to advocate California-style iron-pan amalgamation. Paul reasoned that by adding the chemicals found useful in the Patio Process to the iron pan he would have the best of both processes. In doing so he is generally credited with inventing what became known as the Washoe Pan Process.

The mechanical operations in treating the Comstock ores by the Washoe Pan Process are described in some detail by Eliot Lord.[24] A. D. Hodges, a professional engineer, gave a complete review of milling processes, including a description of a tailings mill, written from first-hand observation.[25] Ernest Oberbillig, in 1967, reviewed both the Washoe Pan and Reese River processes and described the mill layouts, the machinery used, the mechanical procedures, and the chemical additions made to each process.[26] He included a chapter on "The History of Washoe Process Chemistry," but his description is derived from the writings of nineteenth-century metallurgists and professors of metallurgy who analyzed data and expressed opinions much as the proverbial blind man examined the elephant. Their effort was laudable, but they could not complete the picture because they were missing one essential concept: the role of atmospheric oxygen in the process. For that reason, many of their descriptions and hypotheses are suspect, and in some cases are complete misinterpretations.

Many times the early metallurgists achieved improvement in silver recovery in certain mills under certain conditions, only to find that procedures could not be duplicated at other mills or at other times. As one after another of their concepts failed, the inevitability of losses of precious metals was gradually accepted, and 60 or 70 percent recovery considered normal. The standardized Washoe Pan Process was described by T. A. Rickard,[27] and included jaw crushing, wet stamping, settling pans, amalgamating-grinding pans, final settlers, and recovery and retorting of the amalgam. Many descriptions of specific machinery or process adaptations made to improve the process were recorded in the technical periodicals of the day, the *Mining and Scientific Press*, and the *Engineering and Mining Journal*.

Paul described the addition of the Patio Process Chemicals to the existing Washoe pan as "the Patio process perfected." He was also quoted as saying, "I see much working, costing thousands of dollars, which could be demonstrated as a perfect humbug, a nonsensical expenditure of time and money. The more the work is simplified, the more one comes down to common sense, with less of this scientific tomfoolery, the more money will be made."[28] His remark about scientific tomfoolery was countered indirectly by Charles Stetefeldt of Austin, who expressed his feelings by saying of the Comstock mills that they "found it most advantageous never to attack any problem with intelligence."[29] Both men had a point. Simplicity is a virtue, but not without intelligent testing.

Almarin Paul was right that money could be made more rapidly with the Washoe Pan Process than with the Patio or Freiberg process. By 1866, all of the patios and the Freiberg mills had been abandoned, and there was universal acceptance of the pan process. Figure 2 shows several different mechanical designs of the Washoe pan. William Sharon's Union Mine and Milling Company and the Pacific Mine and Milling Company of the Bonanza Kings, as well as many smaller firms, treated their ores by this method for as long as the Comstock Lode was productive.

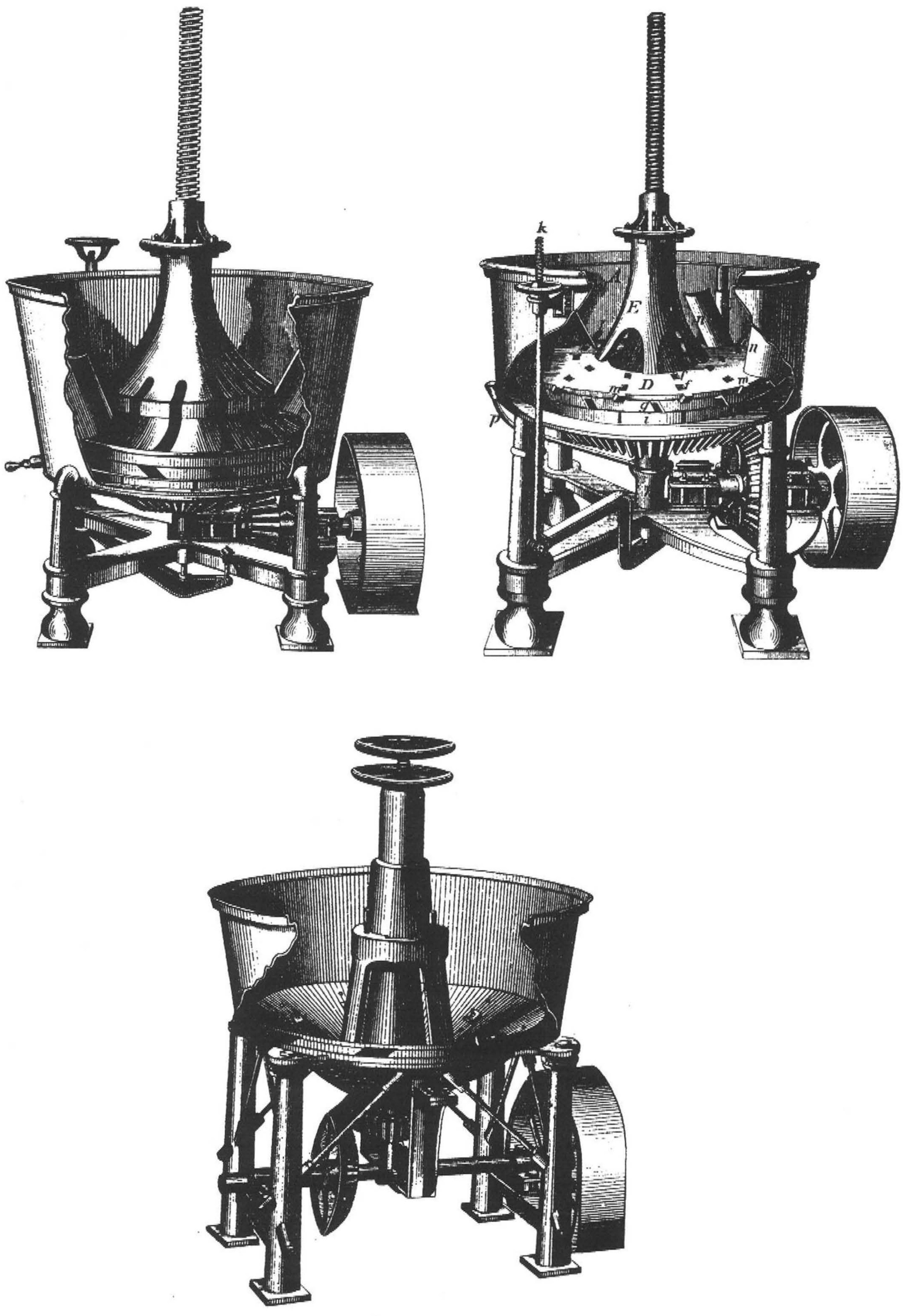


Figure 2. Various designs of the Washoe pan. *Source*: Eliot Lord, *Comstock Mines and Miners* (1883).

THE OPERATION OF THE PAN MILLS

The procedure in pan milling was to crush the ore to the consistency of sand by either wet or dry stamping, and then "deslime" it, a process by which the clay and other fine minerals—the slimes—were washed away from the sand and sent to waste or impoundment. This was done because the slimes were a sticky, muddy mass, and would have incurred extra costs in handling. Unfortunately, although they made up only a small portion of the ore, the slimes often contained a grade of values higher than that in the original ore. Thus, the first losses of gold and silver, often totaling 10 percent or more, occurred even before the sands were sent to the grinding pans for amalgamation.

The sands were put into the grinding pans along with all of the ingredients normally used in the Patio Process: salt, mercury, and copper sulfate (bluestone). This was done on the assumption that the chemicals used in the patios would be just as effective in the pans. In the pans, iron shoes, called mullers, rotated around, grinding the sand to a powder and amalgamating the precious metals with mercury. The amalgam was recovered by washing away the fine sand, and the sand was sent to the same tailings impoundment as the slimes.

THE CHEMISTRY OF THE PAN PROCESS

The mill operators had little knowledge of the chemistry of reactions in the pan or of the quantitative effect of reagent additions on silver recovery. There was no operational standard, and little coordination of milling practice among mills. As a result, "the mill men were laboring under many difficulties in reducing these ores," and "all of these mills have experienced many vicissitudes of fortune" and have "undergone alterations and changes."[30] Numerous fruitless attempts were made to find a magical chemical cocktail that would consistently release the silver for amalgamation in the pans, much as Bartolomé de Medina found when he discovered *magistral* for use in the patios in 1557. Dan DeQuille described the experimentation on the Comstock,[31]

> A more promiscuous collection of strange drugs and vegetable decoctions never before was used for any purpose. The amalgamating pans in the mills surpassed the cauldron of Mac Beth's witches in the variety and villianousness [*sic*] of their contents. Not content with bluestone (copper sulfate), salt, and one or two other simple articles of known efficacy, they poured into their pans all manner of acids; dumped in potash, borax, saltpeter, alum, and all else that could be found in the drug stores, then went to the hills and started in on the vegetable kingdom. They peeled the bark off cedar trees, boiled it down until they had a strong tea, then poured it into the pans. The native sagebrush being the bitterest, most unsavory and nauseating shrub to be found in any part of the world, it was not long before a genius in charge of a mill conceived the idea of making a tea of this and putting it into his pans. The superintendent of every mill had his secret process of working the ore.

None of these "decoctions" improved recoveries in the Washoe pans the way the additions of chemicals did in the Patio Process. The reason for success in the patio was that, being open to the air, it facilitated two separate sets of reactions in sequence in the same ore mass. The first reaction was an oxidation of the silver sulfide by air, catalyzed by soluble copper and/or iron salts (*magistral*), and the second was the reduction of ionic silver or silver chloride to metallic silver by reaction with mercury. These patio reactions, described in the following article on "The Chemistry of the Patio Process," could not occur in a similar sequence in the pans because the pans, enclosed for steam heating, excluded air. Thus, while the higher temperature obtained by the steam accelerated the reactions, the enclosure prevented the beneficial access of air.

The Behavior of Ore Minerals in the Pan

The nature of the silver minerals on the Comstock also brought complications. Comstock ores contained native silver, silver chloride, simple silver sulfide (argentite Ag2S), the complex silver sulfo-salts, stephanite, (5Ag2S.Sb2S3), polybasite, (9Ag2S.Sb2S3), and minor amounts of other silver sulfides. These minerals occurred in variable amounts in various mines, and in any one mine it was usual for the native silver and silver chloride to be nearer the surface (because of natural surface oxidation), and the sulfides to be more prevalent with depth. While silver values in native silver, silver chloride (cerargarite), and argentite could be recovered, the silver values in the more complex silver sulfides (stephanite, pyrargyrite, proustite, polybasite, and others) were partly or largely lost in the tailings.

Oxidation was the chemical process needed to liberate the silver from argentite, and the force of oxidation available in the Washoe pan for that purpose was cupric sulfate (bluestone). In oxidizing the argentite, the cupric sulfate was reduced to cuprous sulfate. Following that, the cuprous sulfate was reduced to metal by the metallic iron of the pan. But there was another consideration. As the cupric sulfate was being consumed in oxidizing the ore, it was also being consumed by the iron of the pan. This created a situation analogous to trying to fill a water bucket with water when it has a hole in the side—you may get it full and you may not—in this case the question was whether the cupric ions could oxidize all of the silver sulfide before they were consumed by the iron of the pan. Therefore, an excess of bluestone had to be added to compensate for that part reduced by the pan. The amount of a proper excess could be determined only by experiment and then only with a consistent ore composition.

Chemical calculations (not available at the time, however) show that, in the absence of air, a minimum of two ounces of bluestone is required to oxidize the sulfur in one ounce of silver present as argentite. If the ore contained 50 ounces of silver per ton, and many times it did, it required a minimum of 100 ounces of bluestone, or 6.25 pounds, for the chemistry to succeed, and proportionately more or less depending upon the amount of sulfur present as argentite. The sulfo-salts were more refractory, and if they were to dissolve they would have required an even larger amount of bluestone.

The mill men could only estimate the proportions of the various minerals in any given batch of ore on any given day, and they did not have the benefit of chemical calculations. The result was that they used standard charges, so many pounds each of salt, mercury, and bluestone per ton of ore, all put into the pans for grinding. The fault in using a standard charge was that the bluestone was not needed for native silver and silver chloride ores, but was crucial for the argentite, and was of little help for the complex sulfides. Thus, if an ore contained mainly native silver and silver chloride, the mill men would have obtained a good result even without bluestone, and declared that the bluestone was a waste. If the ore was predominantly sulfide, the bluestone was critical, and they may or may not have added enough. They were biased toward using less, because it was costly and because the copper in the bluestone was ultimately all reduced to metal and collected by the mercury along with the silver. The more they added the more it would "debase" the bullion, and the bullion would draw a penalty on the market. If they did not add enough, they lost some silver, but the bullion was cleaner and the penalty lower. It was therefore obvious that to make cleaner bullion they should add less bluestone. It was not so obvious that in so doing they would lose more silver. It was left to the mill men to make the judgment of how much bluestone to add. How well they made it, at what mines, and when, could only have been determined by the tailings assays, and these were not readily available for reasons that will be explained later. The results, of course, were reflected in the silver recovered from the tailings impoundments years later, but tailing retreatment was so far in the future that as long as the mill was profitable the losses never made news.

PAN AND PATIO PROCESS COMPARED

The Washoe Pan Process rapidly achieved ultimate recovery of silver from native silver and silver chloride, as well as from that part of the silver sulfide (argentite) for which adequate copper sulfate had been provided. In the Mexican Patio Process, even if the initial addition of copper sulfate had been inadequate, the cupric ion was regenerated by air. It could then oxidize more argentite, and thus the copper was recycled repeatedly as an effective reagent. This meant that there was always cupric copper ion present to react with argentite.

In the Washoe pan, the ore pulp in the covered pan was injected with steam for agitation and heating, and the steam cover kept air out of the pan, and once the cupric copper ion had been exhausted, the dissolution of argentite was at an end. "The Chemistry of the Patio Process," also in this issue, explains these reactions in detail.

The Work of the Janin Brothers

Louis Janin—in retrospect, one of the most competent metallurgists on the Comstock, with his brothers, Henry and Alexis, performed careful experiments in 1868 and laid out the benefits of adding bluestone to the pan.[32] Their work was largely ignored at first because reduction of the bluestone by the iron pan generated copper metal that was caught along with the silver and "debased" the bullion, that is, it reduced the "fineness" of the bullion. Bullion fineness was defined on the basis of 1000 being pure precious metal. Thus, if the fineness was 200, it contained 20 percent gold and silver and 80 percent copper. This "base bullion" (copper being the base metal) had to be refined to remove the copper, and the cost of doing so discouraged the use of bluestone.

It was not until the mid-1870s that the virtue of adding a substantial excess of bluestone to the pans, as counseled by the Janin brothers in 1868, was generally accepted. When that method was used, a higher recovery of silver was achieved in the pans, and the cost of refining the bullion was less than the value of the additional silver recovered from the ore.

An Ulterior Purpose of the Mills

William Sharon came to Virginia City in 1864, sent by W. C. Ralston, president of the Bank of California, to manage the affairs of the local bank. Sharon immediately began a purposeful campaign to control the mining and milling business on the Comstock Lode by lending money to mines and mills at interest rates so low that no other bank could compete, and he thus put the firms under obligation to the bank for repayment. With the panic of 1865, the Bank of California found itself (intentionally or unintentionally) in possession of many mines and mills through foreclosure. Although this presaged dire prospects, a rapid recovery in 1866 bailed out the bank, and the discovery of new ore bodies in the foreclosed properties began a new era of prosperity.

By 1869, the Bank of California controlled all of the leading mines and seventeen mills.[33] William Sharon then established a private corporation, the Union Mine and Milling Company, totally owned by the directors of the California bank. As president of the company, he initiated what was described in some accounts as "a new era in Comstock milling," and "negotiated" highly profitable milling contracts with the mines in favor of the milling company. The mills were able to yield enormous profits to the personal accounts of the directors, who became known as "Ralston's Ring." The contracts thus diverted to the milling firm the profits that should have been paid as dividends on the mining shares. The mill owners became wealthy, but few of the mines ever paid a dividend. Those who profited later advanced the rationalization that the public was not really interested in dividends anyway, but on gambling on the gyrations of the stock market.

To keep the milling profits out of the sight of the public it was the policy of the Ring that no mill, and only a few of the mines, would have assay laboratories. This accounted for much of the uncertainty as to how best to treat the ore. All assays were run at a central assay office, and the results were private information, disclosed only as necessary to the mills, and found more use in stock manipulations. The mill men often worked in the dark regarding the performance of their mills, and it was well known that maximum tonnages were forced through the pans, with relatively large amounts of worthless rock being milled simply to charge the mines with milling costs.[34] This system worked well for the Ring up until 1874; though their fortunes were temporarily threatened in 1869 by depletion of ore, they were bailed out by the discovery of the Crown Point Bonanza in 1870.

By 1870, John Mackay and associates were also developing mines that proved to be profitable, and soon their Bonanza firm began to eclipse the Union Mine and Milling Company. When the Bonanza firm acquired control of the Consolidated Virginia property in mid-1874 their efforts were rewarded with the discovery of the "Big Bonanza." The "Bonanza Kings"—John Mackay, James C. Flood, James G. Fair, and William O'Brien—then mounted a challenge to the Bank of California, the foundation of Ralston's Ring, by establishing the Nevada Bank of San Francisco. They subsequently entered into a ferocious competition for financial control of the Lode.

The Bonanza firm erected two mills under the umbrella of the Pacific Mill and Mining Company. These were the Consolidated Virginia and the California, but the respective mines never owned a share in these mills. Following Sharon's practice, the mills were held as private entities, and ore from the mines was milled at set contract prices. As before, the assay information, true costs, and private profits were never disclosed. R. P. Rothwell, who later became an officer in the American Institute of Mining Engineers, commented in 1879 that "the Comstock Bonanza milling firm contracted to return to the miners 65 percent of the assay value of the ore, but since the assayers were in the employ of the mill this guarantee was as easily complied with as it was worthless."[35] There was no mystery as to the reason, as Lord reported, that only six out of the 103 mining companies on the Comstock Lode ever showed a profit after subtracting stock assessments. The profits garnered by the milling companies were not a part of the public record, but they did show up in personal fortunes. It was not considered good form at that time to refer to private profits.

By 1875, Ralston was in a desperate effort to maintain the Bank of California in financial supremacy on the Lode, and he undertook a series of stock speculations and manipulations, primarily on the shares of the Ophir mine. The bank came to the brink of failure when it became known that the Ophir bonanza was depleted. With no way out, Ralston was in deep financial straits and forced to resign the presidency of the bank. He walked out of his San Francisco office saying, "I'm off for a swim at North Beach." His body was recovered from the water some hours later. John Mackay came down from Virginia City for the funeral. "Couldn't they revive him?" Mackay queried. "For a few minutes, I was afraid they would," William Sharon retorted. Sharon, an officer of the bank, multimillionaire, and recently elected senator from Nevada (1875), had failed to come to the aid of his mentor in his hour of need, and quickly took over administration of the bank.[36]

These accounts show how the secrecy and inadequacy of the sampling and assaying procedures, dictated during the times of greatest productivity of the Comstock Lode, make it nearly impossible to determine how much gold and silver was actually lost in the milling process. The mills were operated as an adjunct to private profits and stock manipulation,[37] and no significant accounts of the performance of these mills was ever found in the professional engineering journal, *Transactions of the American Institute of Mining Engineers*. Apparently there were no professional engineers employed in the two largest Comstock milling organizations, or, if there were, they simply remained silent about the alleged devious practices.

The Tailings Concentrators

It quickly came to the attention of property owners below the major mills that, when tailings were not impounded, the water flowing over their property was carrying along considerable value in precious metals. Using an ancient technology, they began to lay concentration blankets[38] in the streambeds on their properties to catch the values. Many of these were small one-or two-man operations. The heavy ore minerals and bits of amalgam were caught, but most of the valuable slimes flowed over the blankets to waste. Profitability of the small operations was marginal, and a doubling of the price of mercury in 1874, combined with battles over payment for water, put many of them out of business. The Virginia and Gold Hill Water Company demanded that as the water flowed down the gulch sequentially over several properties, each user should pay for it separately. The water company itself later went into the tailing retreatment business, built a dam near Silver City, and led tailings down a long flume to the Woodworth Mill, where they were passed over a blanket table seventeen hundred feet long and nineteen feet wide, the largest of the blanket sluices.[39] In 1866, Gould and Curry built the first major tailing retreatment mill, known as the Reservoir Mill, in Six Mile Canyon, combining blanket concentration and pan treatment of the concentrate.

The concentrates from all of these operations had to be processed for silver recovery, and were bought in competition by the various pan mills. Ultimately, the purchasers put them all back through the pan process, in a somewhat vain hope that on the second pass through the pans, the refractory silver minerals might dissolve. That did not happen, but fortunately the blanket concentrators were able to survive because much of the values they recovered were from the slimes in the ore that had never been through the pans, and because they also recovered bits of amalgam that had escaped the original settling and collection in the mills.

THE TAILINGS MILLS

In the years prior to 1866, the blanket concentrators let the slimes flow over the blankets and go to waste in the belief that the slimes could not be treated in the pans. When it was found that if the slimes were dried first they could be processed in the pans without difficulty, direct treatment of impounded tailings—the combined sands and slimes—went ahead with great initiative. These secondary mills were known as tailings mills. By 1867, large reservoirs were built for impounding both sands and slimes at Dayton, in Gold Canyon, and on the Carson River and served the tailings mills. Two of the largest and most efficient tailings mills were the Lyon Mill at Dayton, first established in 1865 to treat raw ores but converted to a tailings mill in 1869, and the Omega Mill, built in 1877 by the Bonanza firm in Six Mile Canyon, on the site of the old Gould and Curry Mill, to treat tailings from the Consolidated Virginia and California mills.

A. D. Hodges, who was a member of the American Institute of Mining Engineers, gave the most complete professional account of the tailings mills on the Comstock.[40] His was a description of operations at the Lyon Mill, where he was employed from 1872 to 1877. He described the recovery and treatment of tailings, slimes, and blanket concentrates, derived either from the company's reservoir, or purchased directly from smaller mills.

The procedure was to mix the dried tailings or purchased concentrates with water to the desired consistency, place them in heated grinding pans and inoculate them with the chemical additions found best by the Janin brothers. Usually this included bluestone in the amount of ten pounds per ton for sandy ore, and twenty pounds per ton for ore with a large proportion of slimes. The copper from the bluestone, after venting its effectiveness on the sulfide minerals, was all reduced by the pan to copper metal and was caught by the quicksilver along with the gold and silver. The coppery amalgam was recovered from the pan, and the sand and slime residue discharged to the Carson River, once again over blankets. The amalgam was retorted to recover the quicksilver, and the metal remaining was a debased "sponge," a porous, fragile base bullion containing gold, silver, and (largely) copper.

Refining the Base Bullion

The Lyon refinery is described by Hodges.[41] Copper in the base bullion had to be separated from the precious metals, and when the discount demanded by the buyers on the value of gold and silver in the base bullion reached 27 percent, the Lyon Mill built its own refinery. The sponge consisted of two separable and visually identifiable parts, one, a brown, friable material consisting of copper and most of the gold, and the second, a hard, silvery material consisting of about 50 percent each of copper and silver with almost no gold.

The parts were treated individually by a variation of the Zirvogel Process. The friable, brown copper-gold fraction was crushed, separated, and calcined (oxidized) in air to convert the copper to copper oxide. The copper oxide was dissolved in sulfuric acid, leaving a residue of gold. The white sponge could not be easily crushed, so it was roasted with sulfur to convert its content of copper to copper sulfide. It was then crushed and calcined in air to convert the copper to copper oxide, and the silver to silver sulfate. Both the copper and silver were dissolved in sulfuric acid, again leaving a residue (much smaller this time) containing the gold. The gold residues from the two bullions were combined and melted into gold bars.

Silver was separated from the copper in both solutions by precipitating it on metallic copper plates. This gave crystalline silver, which was melted into 990^{+} fine silver bars.

The copper left in solution was recovered as bluestone by evaporation, and the bluestone sold back to the mills for reuse in the pan process. Copper carbonate ore brought from the Walker River area replenished copper losses. The ore was dissolved in sulfuric acid (manufactured at the Lyon plant), and the bluestone was crystallized from the solution.

The availability of the refinery at the Lyon Mill encouraged other pan mills to use more bluestone in their pans in order to increase their silver recovery and gave the Lyon Mill an additional source of profit in selling the bluestone back to the mills. By 1877, the Bonanza firm had put into operation a similar refinery at their Omega Mill.

The Losses of Gold and Silver

Greater sophistication in milling improved silver recoveries as the years progressed, but it never exceeded 75 to 80 percent. Smith[42] concluded that during the twenty-year period 1859 to 1880 the production of gold and silver from the Comstock Lode was $300 million, not including $23 million later recovered from tailings, and that losses were $75 million. His data imply a 75 percent recovery in the first pass through the pans, 6 percent by retreatment of tailings, and 19 percent over-all loss. Later, he added that Rossiter Raymond placed the mill guarantee at 69 percent recovery and their actual recovery at 77 percent, reflecting an additional recovery of 8 percent from tailings, which suggests 22 percent loss. The guarantee, of course, as Raymond said, was meaningless.

Considering the loss to the river of valuable slimes in early operations, the lack of responsible assay controls for much of the period, and the lack of appreciation by many mill operators of the beneficial effect of copper sulfate in improving recovery, it is impossible to accurately estimate the losses of silver and gold. It is most likely near 25 percent. Mill recoveries were always reported, and the mines paid, on the basis of the sands put through the pans, with no account of the tonnage or analysis of the slimes discarded and the consequence of this loss. The slimes were notoriously difficult to recover and treat, and were the first values to disappear down the gulches and into the river with the freshets from the melting snow in the spring.

The loss of mercury and its potentially serious effects on human health ultimately became of even more concern than the loss of the silver, with the Carson River being designated a Superfund Site. DeQuille estimated that in the ten years up to 1876, thirty-six hundred tons of mercury were lost.[43] Smith estimated losses over the entire life of milling on the Lode to be seven thousand tons.[44] As great an environmental disaster as we view that today, it is small in comparison to the hundreds of thousands of tons of mercury dissipated into the streams and valleys of Mexico and Peru by the use of the Patio Process in the previous three hundred years.

THE INDICTMENT

Eliot Lord called the operation of the mills a "waste [of] the mineral resources of the public lands without hindrance."

A. P. Hodges, a professional engineer who was probably closer to the operations than any other who has written about the mills, charged that the secrecy surrounding mill operations was a means of keeping the "magnitude of the private profits out of the public view," and that large tonnages of worthless rock were milled simply to charge costs to the mines.

Almarin Paul said in 1898, many years after he had left the Comstock, that because the mills forced through as many tons of material per day as possible, "the pans never gave over 70 percent recovery." Had they been operated on a more moderate and legitimate scale, they would have recovered "from 85 to 90 percent."[45]

These were opinions of competent first-hand observers. Without careful examination most people could relate to any or all of these views. But do they have real validity?

The Defense

Eliot Lord was right in charging that the mills appeared to be wasting natural resources, but no one had any better milling method to suggest. Furthermore, few cared about conservation in those times. Buffalo were being slaughtered, and the passenger pigeon exterminated, hydraulic mines were spreading waste to fertile valleys in California, and forests were being cleared and burned, all in the name of progress. Some would say that the loss of precious metals was not a waste because these miners saved as much as they could with the means available. That is not an acceptable argument—it was still a waste. If the Comstock tailings had been impounded for another thirty years the flotation process could have more efficiently recovered the values. Could more have been expected of the Comstock miners? In many ways we are no better at preserving natural resources today. Tropical forests are being depleted, the oceans polluted and over-fished, and wildlife habitat destroyed, despite some efforts at conservation.

The Washoe Pan Process had one environmental advantage over the Patio Process. As practiced in Mexico and South America, the patio method brought about a reaction of mercury with the natural silver chloride (cerargarite) in the ore, and formed a fine precipitate of mercurous chloride which was not recoverable. Hundreds of thousand of tons of mercurous chloride simply flowed to waste with the ore residues, and to this day it contaminates the environment of these early mills. On the Comstock, cerargarite similarly reacted with mercury to form mercurous chloride, but in the pans the iron metal ground off the stamps and mullers by natural wear acted to chemically reduce it back to mercury metal. A large proportion of the mercury was saved by this reaction. The losses of mercury that did occur were considered to be primarily mechanical, through "flouring," which is the breaking up of the mercury into extremely fine droplets by the mechanical action of the grinding. Nevertheless, the Comstock losses of mercury are still decried.

Unfortunately, Almarin Paul had no basis for saying that recovery by the pans could have been 85 or 90 percent. Even on retreatment of the ore, the tailings mills themselves never achieved better than 75 percent recovery. Finally, if the pans ever had the potential for 85 or 90 percent recovery it would have been discovered, and the Reese River Process (chlorination roasting) would never have been necessary at Austin and other localities. The limitation was in the mineralogy of the ore and the chemistry of the process, which Paul never understood.

CONCLUSION

The Washoe Pan Process provided an economical, but inefficient, way to recover Comstock silver. Those responsible for operations knew it was inefficient, and men such as the Janin brothers found ways to improve its efficiency. They confirmed the usefulness of copper sulfate for improving recovery from silver sulfides, but because of the variability of mineral composition of ore from different mines, good results could not always be demonstrated. Further, the copper debased the bullion, which lowered its market value, so their teachings were often ignored.

The major primary mills impounded their tailings in the name of conservation, but their successors could not wait for a better technology, and in a vain hope reworked them by the same inefficient process. This time the residues went into the river. This was not a wanton disregard for conservation of the natural resource, but simply a strong motivation to recover more values, without a proper knowledge of how to do it.

No one in the nineteenth century realized the magnitude of the health problem related to mercury. It would be almost a century before mercury poisoning reached the national spotlight. In their ignorance, the mill men of the time saw no reason to give up the valuable help they found in the use of mercury, and it was not then considered to pose a major health problem. Impoundment of all tailings would have provided a later opportunity for mitigation of the mercury problem as well as facilitating recovery of additional precious metal values.

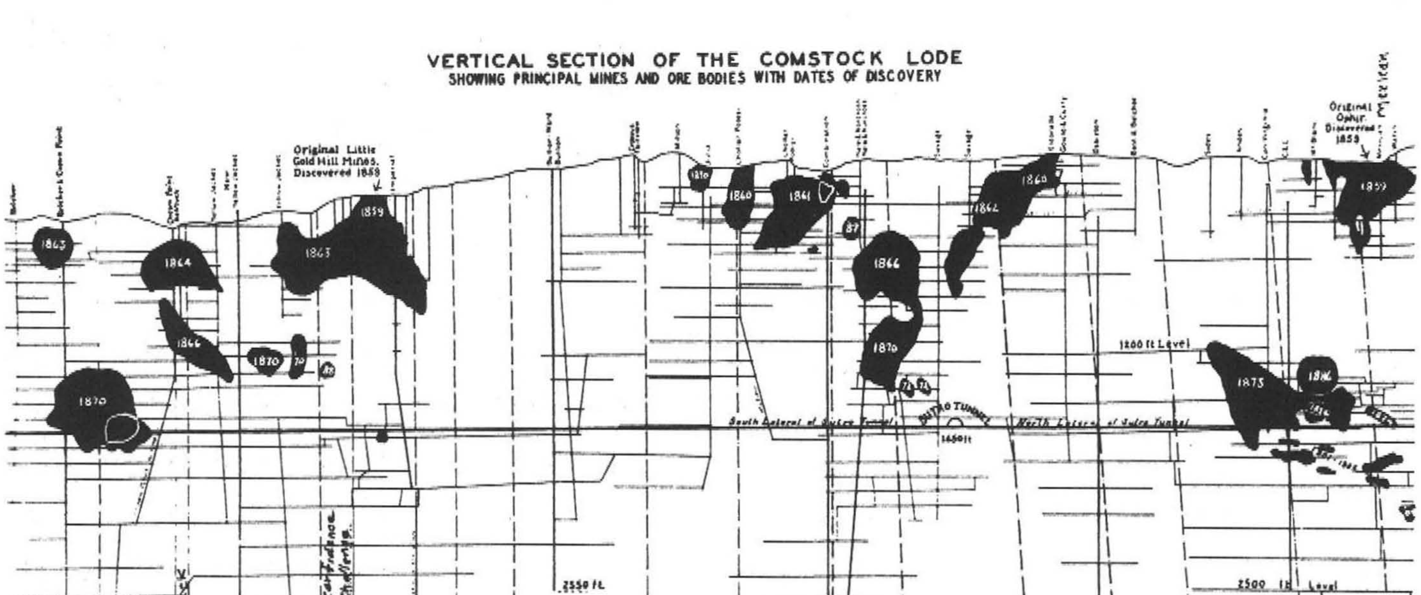


Figure 3. Cross section of the Comstock. *Source*: Eliot Lord, *Comstock Mines and Miners* (1883).

NOTES

[1]Grant H. Smith, "The History of the Comstock Lode," *Nevada State Bureau of Mines*, 37: 3, (1943).

[2]The Pactolus is a river in Asia Minor, a tributary of the Hermus, where auriferous sands furnished the legendary riches of King Croesus (c. 560 BC), and where ancient gold refineries are now being excavated and studied by the British Museum. See A. Ramage and P. Craddock *King Croesus's Gold: Archaeological Exploration of Sardis*, (Cambridge: Cambridge University Press, 2000).

[3]Eliot Lord, *Comstock Mines and Miners* (1883; Berkeley: Howell-North Publishing Co., 1959), 115-16.

[4]U. S. Congress, Senate, Subcommittee on Superfund Ocean and Water Protection, Hearing No. 101-586 (Carson City, Nevada, 12 February 1990, Senator Harry Reid presiding), 101st Cong., 2nd sess. (Washington, D.C.: U.S. Government Printing Office, 1990).

[5]Henry DeGroot, *The Comstock Papers*, Paper 12 (Reno: Grace Dangberg Foundation 1985), 71. Also see *Mining and Scientific Press*, issues of late 1876 and early 1877, for the complete series of twenty papers.

[6]Smith, "History of the Comstock Lode," 17.

[7]*Ibid.*,16.

[8]Myron Angel, ed., *History of Nevada* (1881; reprint Berkeley: Howell-North Publishing Co.,1958), 68.

[9]DeGroot, *The Comstock Papers*, Paper 12, 59.

[10]*Ibid.*, Paper 12, 77.

[11]Angel, *History of Nevada*, 68.

[12]Wells Drury, *An Editor on the Comstock Lode* (Palo Alto: Pacific Books, 1948), 98.

[13]Smith, "History of the Comstock Lode," 87.

[14]Swift Paine, *Eilley Orrum* (Palo Alto: Pacific Books, 1929). This is a fictionalized but largely accurate account of Eilley Bowers's life. Also see Drury, *Editor*, 622.

[15]Smith, "History of the Comstock Lode," 87, 88.

[16]*Ibid.*, 82. The barrel process consists of amalgamating the ore in a rotating barrel rather than on amalgamation plates.

[17]Smith, "History of the Comstock Lode," 81.

[18]*Ibid.*, 81.

[19]*Ibid.*, 85.

[20]*Ibid.*, 45.

[21]E. J. Michal, "Charles A. Stetefeldt, Central Nevada's Pioneer Silver Metallurgist," paper presented at Mining History Association Meeting, Tonopah, Nevada, 2000.

[22]Smith, "History of the Comstock Lode," 81, 85.

[23]*Ibid.*, 43.

[24]Lord, *Comstock Mines and Miners*, 82-88, 117-21.

[25]A. D. Hodges, "Amalgamation at the Comstock Lode, Nevada,"*Transactions of the American Institute of Mining Engineers* (hereafer cited as *Trans. AIME*), 19 (1890-91), 195.

[26]Ernest Oberbillig, "Development of the Washoe and Reese River Processes," *Nevada Historical Society Quarterly*, (Summer 1967), 5-43.

[27]T. A. Rickard, *A History of American Mining* (New York: McGraw Hill, 1932).

[28]Smith, "History of the Comstock Lode," 4

[29]Michal, "Charles A. Stetefeldt," 82.

[30]Angel, *History of Nevada*, 54

[31]Dan DeQuille, *The Big Bonanza* (1876; (New York: Alfred Knopf, 1953).

[32]Hodges, "Amalgamation," 209.

[33]Smith, "History of the Comstock Lode," 51.

[34]Hodges, "Amalgamation," 206.

[35]R. P. Rothwell, "Cost of Milling Silver Ores in Utah and Nevada," *Trans AIME*, 8 (1879), 559.

[36]George D. Lyman, *Ralston's Ring* (New York: Scribner & Sons, 1955), 308

[37]Hodges, "Amalgamation," 205.

[38]Concentration by blankets was an ancient art as we know from the story of Jason and the Golden Fleece, which refers to the gold caught in blankets of sheep's wool. Sand mixtures flowing

over the rough blankets deposited the valuable heavy minerals in the interstices of the fabric, from which they could be shaken or washed out from time to time.

[39]Hodges, "Amalgamation," 210.

[40]*Ibid.*, 25.

[41]A. D.Hodges, "The Process Used at the Comstock for Refining Coppery Bullion Produced by Amalgamating Tailings," *Trans. AIME*, 14 (1885), 731.

[42]Smith, "History of the Comstock Lode," 256.

[43]DeQuille, *The Big Bonanza*, 98.

[44]Smith, "History of the Comstock Lode," 257

[45]Almarin Paul, "Great Mining Enterprises to Small Ones," *Mining and Scientific Press* (18 October l898), 353.

The Chemistry of the Patio Process

EUGENE J. MICHAL

BACKGROUND

The Patio Process evolved out of arrastra amalgamation, which was the procedure used in Mexico and South America for nearly three hundred years to recover silver from its ores. In arrastra amalgamation, the ore was ground to a fine sand and slime in a circular stone-lined pit—the arrastra—in the presence of mercury. The mercury collected the silver (and gold) to form an amalgam, and the barren residue was washed away. The amalgam, containing the silver and gold, was recovered and retorted (distilled) to recover the mercury for re-use.

When the silver in the ores existed as native silver or silver chloride (cerargyrite, AgCl), the recovery of silver by this method proceeded reasonably well; but it was recognized that even after the grinding was complete, the longer the mercury was stirred in contact with the ore, the greater the silver recovery. To prolong this contact, the ground ore was taken out of the arrastra, dewatered to the consistency of thick mud, placed on a patio, and formed into a cake known as a torta. The torta was then mixed, along with additions of mercury, for as long as the mercury's increasing consistency (thickening) showed that it was still gathering silver. This usually took several days. When the *azoguero,* the amalgamator, decided that no more silver was being recovered, the mud and sand were washed away from the heavier amalgam.

As the Mexican silver ores began to be mined from deeper levels in the 1550s, they showed less native silver and chloride of silver and more sulfide of silver, and less silver was recovered by the usual treatment in a patio. A Spaniard, Bartolomé de Medina, at Pachuca, experimented with ways to improve the recovery. He is generally credited with the 1557 discovery that the addition of common salt (NaCl) and the calcined residue of a copper ore—at that time called magistral, and consisting of a mixture of cupric and ferric sulfates and oxides—to the torta would greatly accelerate the reduction of silver and its absorption into the mercury. This became known as the Patio Process.[1]

The amount of sodium chloride added was usually about 5 percent of the weight of the ore, and when added to the moisture in the torta it created a solution essentially saturated with salt. The magistral addition, expressed in terms of the active constituent, copper sulfate, was in the order of five pounds per ton of ore, added according to the judgment of the azoguero, and according to the results he obtained in repetitive treatments.

The Patio Process, as it evolved, was used on silver ores for more than three hundred years. While it was an improvement over simple amalgamation, it was never entirely satisfactory for sulfide ores. Much experimentation was done with various chemicals and treatment methods, but the results were erratic, and reproducibly high recoveries were never obtained. This was frustrating to the azogueros and even to the learned professors at the leading mining schools.

Professor John Percy, known as the father of English metallurgical literature wrote in 1880, probably out of sheer frustration, that "of all of the branches of metallurgy, that of which silver forms the basis is the most extensive, the most varied, and the most complicated."[2] As far as the chemistry of the Patio Process is concerned, that is still a true statement.

Professor Carl Schnabel offered what the writer found to be an incomprehensible discussion of the chemistry of the Patio Process and concluded, "Exact knowledge of the patio reactions can only be determined by further research."[3] The research has never been completed.

One reason for the lack of reproducibility encountered is that the process was applied to a great variety of silver ores at different localities and having different mineral compositions. Each of the different minerals responded differently to given process conditions. The process conditions—the fineness of grind of the ore, the atmospheric humidity, and the temperature—also varied. This led to results that did not yield to rational explanations. Many eminent metallurgists of the late nineteenth century, professors at major universities, and authors of textbooks on silver, offered detailed but often confusing and conflicting explanations of what they thought went on in the patio, and universal agreement was never reached. The miners of the day tried to make the patio a one-size-fits-all process, and then attempted to explain the results, which were sometimes good and sometimes bad, but the explanation was often an exercise in futility.

A fundamental deficiency of the science of the time was that an understanding of the thermodynamic properties of substances and the role of ionization, pH (hydrogen-ion concentration in the liquid), and oxidation-reduction potentials in chemistry had not been developed. These tools are available today, but much of the essential work on understanding the Patio Process still has not been done because there is no economic reason for doing so. The process is obsolete because it is slow, labor intensive, and costly, and because concentration of ore by flotation, followed by smelting, has provided a more efficient and economical treatment for sulfide ores.

The Operation of the Patio

There are at least three technical descriptions of the Patio Process in the annals of the American Institute of Mining Engineers. These are descriptions by Manuel Vallerio Ortega,[4] Miguel Bustamonte,[5] and Richard Chism,[6] and they cover the operations in detail. While these descriptions differ slightly, there is a reasonable degree of uniformity as to the mechanical operations, if not the chemistry. Ortega states,

> The ore extracted from the mine is sorted by the pepenadores, who break the large pieces of rock with hammers, rejecting those which contain no ore, set aside the very rich to be smelted, and deliver the rest to be pulverized for direct amalgamation in the patio. The broken lumps, about fist-size, are first ground in Chilean mills, and then reduced in arrastras, or tahonas, to fine slime.
>
> After the slime, or lama, has acquired a suitable consistency by evaporation, through the sun's heat, of a part of the water which it contained, it is spread upon the patio or amalgamating floor, where it is mixed with five or six percent of common salt. The next day a certain amount of bluestone (copper sulfate) is added; and immediately afterwards, mercury, in the proportion of eight parts to one of silver contained in the mineral, is squeezed through a piece of thick cloth or chamois skin and spread over the pulp or torta. These chemicals are thoroughly mixed with the slime by means of horses or mules trampling the torta, an operation called the repaso, and repeated daily until the treatment is finished. The time required is from two to five weeks, depending on the quality of the ore, the temperature of the locality, and the period of the year.
>
> Amalgamation being finished, the torta is transferred to deep circular stone vats, or settlers, through which water is passing, agitated by a revolving paddle. The amalgam and other heavy metalliferous materials collect in the bottom, while the light, earthy impurities are held in suspension and carried away.
>
> The fluid amalgam thus obtained is squeezed through canvas bags, whereby the excess mercury is forced out, and there remains a solid or pasty argentiferous amalgam, containing about one fifth of its weight in silver. This is compressed into triangular segments, which are transferred to the quemaderas, or retorting houses, for the separation of mercury by heat.

The time required to complete the process was heavily dependent on the degree of mixing of the ore with the reagents on the patio, i.e., the more mixing, the shorter the time. Philips reported that "the top of the torta was always in a more advanced condition than the bottom."[7] That was a clue to the chemistry of the patio, an indirect indication that atmospheric oxidation was an essential element in the process. But this need for oxygen apparently was not understood. Another clue to the chemistry was a statement by Bustamonte that, "the most effective and economical of all [copper sulfate preparations] is the impure sulfate of copper with a large quantity of iron sulfate, known as 'magistral.'"[8] The magistral contained ferric sulfate, and although the role of the ferric iron in the patio was not understood, it did improve the process. No one even attempted to explain why. Bustamonte further stated that mixing the torta, whether by shoveling or treading, was also important. Henry Collins reported that the consistency of the torta was required to be such that "the horses' hoof prints do not run together."[9] Although unrecognized at the time, these deep hoof prints increased the surface area exposed to the air, and this was beneficial to the process. All of these clues pointed to the necessity for exposure of the *lama*, the slime, to the oxygen of the atmosphere to be most successful.

The darker side of mixing was that the treading animals acquired festering sores on their hooves and legs and absorbed soluble mercury and copper into their systems, in part through their skin, and in part because of their uncontrollable tendency to lick the torta for salt. They soon died. Often, the tortas sat for weeks with relatively little mixing, because "horses were more expensive than time." To the horses' benefit, they were used as sparingly as possible. The treading by horses can be rationalized as an improvement to the process only when it is realized that, prior to 1793, barefoot Indians were doing the treading, or were turning the torta with wooden spades, with similar deadly physiological results.

The Role of Sodium Chloride

The reduction of silver chloride to silver metal by mercury in the torta can be represented by the generally accepted equation:

$$2AgCl + 2Hg = Hg_2Cl_2 + 2Ag \quad (1)$$

As elementary as this equation may seem, it implies a reaction between two solid substances, and as such would be notoriously slow at ordinary temperatures. This was part of the problem in the torta before salt additions were tried. Medina's new metallurgy, with the addition of salt, converted the water in the torta to an electrolyte, and accelerated the reaction. The solution of sodium chloride, in the interstices of the ore particles, dissolved (ionized) silver chloride to furnish about one gram per liter of dissolved (ionic) silver:

$$AgCl\ (s) = Ag+\ (Aq,\ 1gpl) + Cl^-\ (Aq) \quad (2)$$

where (Aq) means the dissociated ionic form and (s) the solid form. Aqueous diffusion, helped by warmth of the torta, then facilitated the reaction of silver ions with mercury:

$$Ag+\ (Aq) + Hg\ (s) = Ag\ (s) + Hg+\ (Aq) \quad (3)$$

and the resulting precipitated silver was taken up by the excess mercury added to the torta. The mercury ions which were in the solution combined with chloride ions from the salt to form an insoluble precipitate of finely divided mercurous chloride that remained in the ore pulp:

$$2Hg+\ (Aq) + 2Cl^-\ (Aq) = Hg2Cl2 \quad (4)$$

The net result was as shown in equation (1), and the finely divided mercurous chloride was flushed into the environment when the torta was washed. The stoichiometry of this equation was confirmed experimentally many times, and it represented a loss of about 1.85 ounces of mercury per ounce of silver recovered (this is the ratio of the atomic weight of mercury to that of silver). Over the period of several hundred years, hundreds of thousands of tons of mercurous chloride were delivered into the arroyos, canyons, and flats of the silver-mining districts of Central and South America. The same loss of mercury occurred near certain nineteenth-century silver mines in the United States where arrastra amalgamation was practiced.

Silver Reduction by Added Metals

Once the silver was converted to the ionic form, as in equation (2) above, it could also be reduced to metal by elements other than mercury. This discovery led to the use of elemental copper, tin, lead, and iron added to the torta by various amalgamators, usually in the form of metal powders or amalgams, to reduce the silver. These were used in various mechanical adaptations known as the Cazo and Krohnke (stirred kettles), the Freiberg (rotary barrel), and the Washoe (pan). They all carried out the same fundamental reduction of ionic silver to metal and its collection in mercury. These other metals, when used at the proper time and sequence of the operation, resulted in considerable savings of mercury.

Silver Reduction by Ionic Species

Ionic silver in the torta can also be reduced by ionic species in solution. The Zirvogel Process, for example, uses ferrous iron:

$$Ag^{+} + Fe^{+2} = Ag^{0} + Fe^{+3}$$

Organic materials can also reduce ionic silver. At the silver refinery at Kellogg, Idaho, dextrose is used to reduce silver chloride.[10]

$$24AgCl + C_6H_{12}O_6 + 24\ NaOH = 24Ag + 6CO_2 + 18\ H_2O + 24\ NaCl$$

Other organics were available in the torta, including the inevitably emplaced animal products (urea, ammonia, and biomass) and alcohols from the fermentation of the biomass.

THE ROLE OF MAGISTRAL

Magistral was a generic name for roasted copper-iron pyrites. The original mineral could have been chalcopyrite or any one of several other copper-iron sulfides. The roasting conditions for preparing magistral were not specified, but we know that it had to be carried out at a temperature which would oxidize the sulfur to sulfate, but not expel it as sulfur dioxide, which would be known as a "dead roast." Present knowledge of the temperature range of stability of the sulfates indicates that this would be at about 600 degrees centigrade or slightly higher (a dull red heat).

The improvement brought about by the addition of magistral to the patio was never perfect, and much effort was expended on experimentation to get the best possible result. Whatever was done, it always proved better to hand-sort the heavy, rich sulfide silver out of the ore initially and smelt it separately, or, if not, to treat the patio tailings by gravity concentration to recover the heavy sulfides for later smelting. If smelting was not convenient, the sulfides could be roasted and the roasted product returned to the patio for retreatment. Chism gives an excellent example of how these procedures were managed at San Dimas.[11]

The best metallurgists of the day had tried to explain why magistral, with its two effective constituents, cupric and ferric sulfates, was effective much of the time, but not all of the time. The words of Chism were both accurate and prophetic when he wrote,

> In the consideration of this process, I have made no effort to investigate its reactions. Several learned chemists have, I believe, written on this subject, but I do not know that they have even approached an agreement. I may well be excused from entering into a discussion which has already proved itself so very unprofitable.

The learned chemists, however, were undeterred and their discussions continued well into the twentieth century until the demise of the process. The discussions were left fallow for many years, but in the light of developments in hydrometallurgy in the last half of the 1900s, hypotheses can now be set forth that explain with somewhat greater certainty the important mechanisms of the chemistry of sulfide dissolution. Copper sulfate was known to be an effective accelerator of the amalgamation of silver, and sulfide ores were the primary beneficiaries of its action. It was also recognized that its usefulness was confined to the simple sulfide, argentite (Ag_2S). Sulfo-salts such as proustite ($3Ag_2S.As_2S_3$) and stephanite ($5Ag_2S.Sb_2S_3$) were decomposed only slightly, if at all, in the torta, or even in the boiling waters of the Washoe Pan Process used on the Comstock Lode. At Austin, Nevada, the complex ores made the Washoe Pan process recoveries unacceptable, and forced the use of a new metallurgy called the Reese River Process. In this process, the entire ore was roasted with salt to convert the silver to a chloride before being placed in the pans for amalgamation.

THE OXIDATION OF SULFIDE MINERALS

The oxidation of silver sulfide (argentite) by atmospheric oxidation certainly occurs in nature, as many silver-ore deposits show elemental silver and silver chlorides near the surface and sulfide ores at depth. But oxidation of sulfides in nature is a slow process, and even then it probably benefits by catalytic help. Vincent Gianella, a geology professor at the University of Nevada's Mackay School of Mines, would say to students visiting mines in central Nevada in the 1940s, "Do you see those clouds of dust blowing off that desert playa? They are heading for the hills, bringing salt to convert silver sulfides to chlorides." Of course, after the salt was dropped, a little rain helped in the oxidation of copper sulfide minerals to furnish cupric and ferric ions, and after a few thousand years the conversion of silver sulfide to chloride really did happen:

$$2Ag_2S + 4O_2 = 2Ag_2SO_4 \quad \text{(oxidation), and}$$

$$2Ag_2SO_4 + 4NaCl = 4AgCl + 2Na_2SO_4 \quad \text{(conversion)}$$

This natural oxidation process, too slow for the miners of the New World in the 1550s, was what inspired Medina to devise the Patio Process, a means for breaking the bond between silver and sulfur. Unfortunately, while it did appear to work for the simple sulfide, it did not work for the complex sulfides.

The chemistry of the Patio Process was not understood, but many of the leading metallurgists of the late 1800s attempted to explain it. The equations they wrote usually showed a double decomposition reaction in which the sulfur was taken from the silver by cuprous chloride, which had been formed by the reaction between common salt and cupric sulfate.[12] They were vague on how the cupric ion became cuprous. Actually, it would have required a reducing agent to accomplish this, but they gave no specific reference as to how it was done. Schnabel[13] and Rammelsberg[14] formulated similar equations using cuprous chloride to explain the decomposition of the complex silver sulfo-salts, proustite and pyargyrite. One would have to question whether they ever ran the experiments. It is likely that they would have failed.

For an answer to the question of what really works in hydrometallurgical processing of sulfides we can look to work done in the mid-twentieth century. There are three well-known patented processes for the dissolution of copper sulfides, the Cymet,[15] Duval,[16] and Cominco.[17] All operate in acid chloride media. The fundamental work done in developing these processes, and more specifically the work done on chalcocite (Cu_2S), can point to the most likely reactions of Ag_2S in the patio or the pan process because of the chemical similarity in the two compounds.

Eh-pH diagrams (graphical plots of the chemical potential of a solution versus its acidity) show that the oxidizing potentials of cupric and ferric ions in acidic solutions are very high, making them aggressive agents for the oxidation of sulfide minerals. This has been proven experimentally, and the abovementioned processes utilize this effect in treating copper sulfide ores to prepare solutions for electrolytic copper recovery.

Chalcocite (Cu_2S) has been shown to dissolve in two steps:[18]

$$Cu_2S + 2Fe^{+3} = Cu^{+2} + 2Fe^{+2} + CuS \quad \text{and}$$

$$CuS + 2Fe^{+3} = Cu^{+2} + 2Fe^{+2} + S^0$$

$$Cu^2S + 4Fe^{+3} = 2Cu^{+2} + 4Fe^{+2} + S^0 \quad \text{(net result)}$$

Many investigators have confirmed the formation of elemental sulfur as a result of these two oxidative reactions. (The sulfur can proceed on to sulfuric acid in the presence of air and moisture, as can be observed in the acid drainage from outdoor sulfur piles. However, it is a slow process at ordinary temperatures, even though in this case it would be favored by the extremely fine particle size of precipitated sulfur.)

Paralleling the chalcocite reactions, we can now propose an equation for the dissolution of argentite in the patio in the presence of magistral. The sulfide oxidation reactions proceed through electronic valence changes among the key elements iron, sulfur, and oxygen to accomplish the practical aim of dissolving the silver. Bustamonte noted that magistral with a high content of ferric iron was the most effective of all reagents, so the following reactions seem reasonable:

$$2Ag_2S + 2Fe_2(SO_4)_3 = 2Ag_2SO_4 + 4FeSO_4 + 2S$$

$$4FeSO_4 + 2H_2SO_4 + O_2(\text{air}) = 2Fe_2(SO_4)_3 + 2H_2O$$

$$2S^0 + 3O_2 + 2H_2O = 2H_2SO_4$$

$$2Ag_2S + 4O_2 = 2Ag_2SO_4 \quad \text{(net result)}$$

Note that the ferric iron is, in effect, a catalyst for the oxidation of sulfur by air. While these equations show the reaction of sulfide with ferric ion, a completely parallel set of reactions can be written for cupric ion:

$$Ag_2S + 2NaCl + 2CuSO_4 = Ag_2SO_4 + Cu_2Cl_2 + Na_2SO_4 + S^0$$

In ionic terminology, the essential force in this reaction is:

$$2Cu^{+2} + S^{-2} = 2Cu^{+} + S^{0}$$

and, of course, as with the ferrous iron reaction shown above, the cuprous copper goes on to be oxidized by air to cupric ion and the sulfur to sulfuric acid. Ferric ion is the more powerful of the two oxidants, but it is effective only at a pH lower than 3, above which the iron would precipitate as a hydroxide.

The cupric ion (added as bluestone, CuSO4.5H2O) is in reality the essential oxidant in the Washoe Pan Process. In the Patio Process both cupric and ferric ions are oxidizing agents. The utility of cupric ion, although not as powerful, is due to its availability at higher pH (hydrogen ion concentration, or acidity). The discussion of the effect of pH in the patio cannot be entered into here because no data are available on the real systems. In fact, if a high acidity could have been maintained in either the patio or the pan, the complex silver arsenic-antimony minerals may have been more completely dissolved. But such acidity was obviously impossible to maintain in an iron pan, as the acid would have been consumed by the pan itself.

The soluble silver sulfate formed in these dissolution reactions precipitates as silver chloride in the torta, and is reduced to metal by the elements present, such as mercury, copper, iron, etcetera (whatever may have been added). From the above, we can now conclude:

> Hydrometallurgical processing of silver sulfide ores should be a two-step metallurgy, the first step being to separate the sulfur and dissolve the silver with an oxidant (in the patio, it is air, catalyzed by copper or iron), and then in the second step precipitate the silver with a reductant (in the patio process, the metals mercury, copper, or iron). The addition of the oxidant and reductant at the same time, as in the Washoe Pan Process, would short-circuit their respective actions.

Was this recognized in the Patio Process? No, but this was because the torta was not a very well-mixed mass. The reductants were added at variable times, time was of less concern, and both reactions could be accommodated in sequence, even if it had not been planned that way. Was it recognized in the Washoe Pan Process? No, and because the Washoe pan was a well-stirred reactor, the condition to oxidize the silver sulfide was provided only by the initial cupric copper sulfate addition, and no opportunity was given for cuprous copper to act in a catalytic capacity with air to regenerate cupric copper and dissolve more silver sulfide.

Actually, the instant the copper sulfate was added to the pan, the iron of the pan began to reduce all cupric ions in contact with the iron to metallic copper, while another part of the cupric ions, those in contact with argentite, were oxidizing silver sulfide to sulfate. These two reactions competed for the available oxidizing power of the copper sulfate, and it was only a matter of time before the cupric ions were all consumed. Thus, adding a considerable excess of the copper sulfate (bluestone) was necessary to insure that enough was available to oxidize all the silver sulfide (argentite). It is easy to see that in the earliest milling operations, Washoe pan recoveries were very likely lower than they could have been since the use of bluestone was restricted because of its cost and the need to avoid "debasing" the bullion, which incurred an extra refining charge.

Recoveries might have been better in the Washoe Pan Process if, for example, the bluestone had been first added to the ground ore in a wooden vessel and agitated with air to reduce the silver sulfide to chloride. The reaction could then have been completed by filtering out the cuprous chloride in solution and transferring the chloridized ore to the steel pans for reduction of the silver chloride to metal. However, as practiced on the Comstock, all of the copper sulfate added to the pan eventually was reduced to copper metal in the pan. The mercury gathered up the copper along with the silver, and the copper had to be removed by a refining process.

The metallurgy was often more complicated than that addressed above since there exist many more silver minerals than are mentioned in this text, and, because of differing kinetic mechanisms, not all behave in the same way and their relative response could only have been determined by experiment. Furthermore, the reactions cited above show a dependency on pH, that is, acid is either consumed or generated by the various reactions at various times and influences the degree of completion of the reaction. This was a factor neither understood nor addressed in the literature of the Patio Process.

NITROGEN COMPOUNDS IN THE PATIO

The role of nitrogen compounds in the patio must also be addressed. These were undoubtedly introduced into the torta by animal excrement, primarily as urea and ammonia. Six or eight horses, trampling in a circle for some hours would undoubtedly relieve themselves, particularly as the tenders watered them well to discourage them from licking the torta. The operators probably regarded this as a nuisance and did their best to prevent it, but it may actually have been beneficial to the chemistry. Animal wastes contain free ammonia and urea, and the urea can be converted to ammonia by a natural enzyme.[19] Ammonia dissolves silver chloride to form a soluable complex ion, and this ionization of silver certainly could have been beneficial in transferring the silver to the mercury. Nitrates would also be introduced by the animals, and given proper acidity of the patio, they too could play a role in sulfide decomposition.

These are only a few hypotheses concerning the effect of animal products in the patio. The reader may imagine what additional chemical reactions could occur because of the dozens of different organic chemicals in animal waste. Bacteria also can play a significant role in sulfide oxidation, and it should be noted that solid animal waste consists of up to 30 percent by weight of the skeletal remains of intestinal bacteria.

Summary

The Patio Process actually carried out two separate sets of chemical reactions in sequence in the same ore mass, the torta. The first was the oxidation of sulfide silver by air, catalyzed by copper or iron sulfate, and the second was reduction of ionic silver by mercury, copper, iron, or other ionic or organic species, to be collected in the mercury. The Washoe pan, on the other hand was strictly a reducing device, the iron of the pan being the reducing agent, and little or no oxygen was available to assist the cupric ion in decomposing the sulfide. A hot solution in an enclosed pan, agitated with steam jets, effectively kept the air out of the pan, and the copper sulfate additions were of assistance only as long as the cupric ion lasted in the presence of the iron of the pan. Recovery of silver from native metal, silver chloride, and that part of the silver sulfide (argentite), to the extent that adequate copper sulfate was added, was achieved, but the more complex silver minerals were unchanged and lost in the tailings.

The Patio Process in all of its modifications is too complex to define clearly, and there is no useful purpose in doing so. The chemistry of the process is a vague and elusive subject, the study of which is of more value as an intellectual exercise than for practical use. It can be likened to a game of chess, with many pieces, a host of potential moves, and consequences difficult to predict.

NOTES

[1]*The Pyrotechnia of Vanoccio Biringuccio* (1535),C. S. Smith, transl., American Institute of Mining Engineering, Seely Mudd Series, 1942. Medina's process may actually have been discovered earlier. The reference describes a process in which " silver ores [were] ground while being moistened with water, or vinegar, in which has been dissolved corrosive sublimate, verdigris (copper acetate) and common salt"(p. 142). It is probable that Medina had heard of this procedure in Spain, ran experiments on the Mexican ores, and showed that it gave an improvement in amalgamating the silver.

[2]John Percy, *Metallurgy, the Art of Extracting Metals from their Ores*, (London: J. Murray, 1880).

[3]Carl Schnabel, *Handbook of Metallurgy* (New York: MacMillan, 1898), 771.

[4]Manuel Vallerio Ortega, "The Patio Process for Amalgamation of Silver Ores," *Trans. AIME*, 32 (1902), 276.

[5]Miguel Bustamonte, "A Study of Amalgamation Methods: II. The Patio Process," *Trans. AIME*, 32 (1902), 484.

[6]Richard E. Chism, "The Patio Process in San Dumas, Mexico," *Trans. AIME*, 11 (1882), 61.

[7]John Arthur Philips, *Elements of Metallurgy*, ed. 3 (London: Chas. Griffin & Co., 1891)., 744

[8]Bustamonte, "A Study of Amalgamation," 484.

[9]Henry F. Collins, *The Metallurgy of Lead and Silver: Part II, Silver* (London: Griffin Co. 1900), 48.

[10]C. G. Anderson, "The Non-cyanide Recovery of Silver Using Nitrous-Sulfuric Acid Catalyzed Pressure Oxidation," (paper presented at Society of Mining Engineers Annual Meeting, Denver, 24-27 February 1997).

[11]Chism "The Patio Process,"61.

[12]Eds, "The Kroehnke Amalgamation Process," *Mining and Scientific Press*, (16 December 1876), 399.

[13]Schnabel, *Handbook*, 77.

[14]Collins, "The Patio Process,"*The Metallurgy of Lead and Silver: Part II, Silver*, 48.

[15]P. R. Kruesi, E. S. Allen, and J. L. Lake, "The Cymet Process, Hydrometallurgical Conversion of Base Metal Sulfides to Pure Metals," (paper presented at Conference of Metallurgists, Halifax, Nova Scotia, 1972).

[16]G. E. Atwood and C. H. Curtis, Duval Corporation Patents 3,785,944 and 3,879,272 (1974).

[17]"The Sherritt-Cominco Process, Parts I, II, and III," *Canadian Mining and Metallurgical Bulletin*, 2 (1978), 105.

[18]J. E. Dutrizac and R. J. C. MacDonald, "Ferric Iron as a Leaching Medium," *Minerals Science Engineering*, 6:2 (April 1974), 59.

[19]Philip B. Hawk and Olaf Bergeim, *Practical Physiological Chemistry* (Philadelphia: Blakiston & Son, 1937), 594.

Charles A. Stetefeldt
Central Nevada's Pioneer Silver Metallurgist

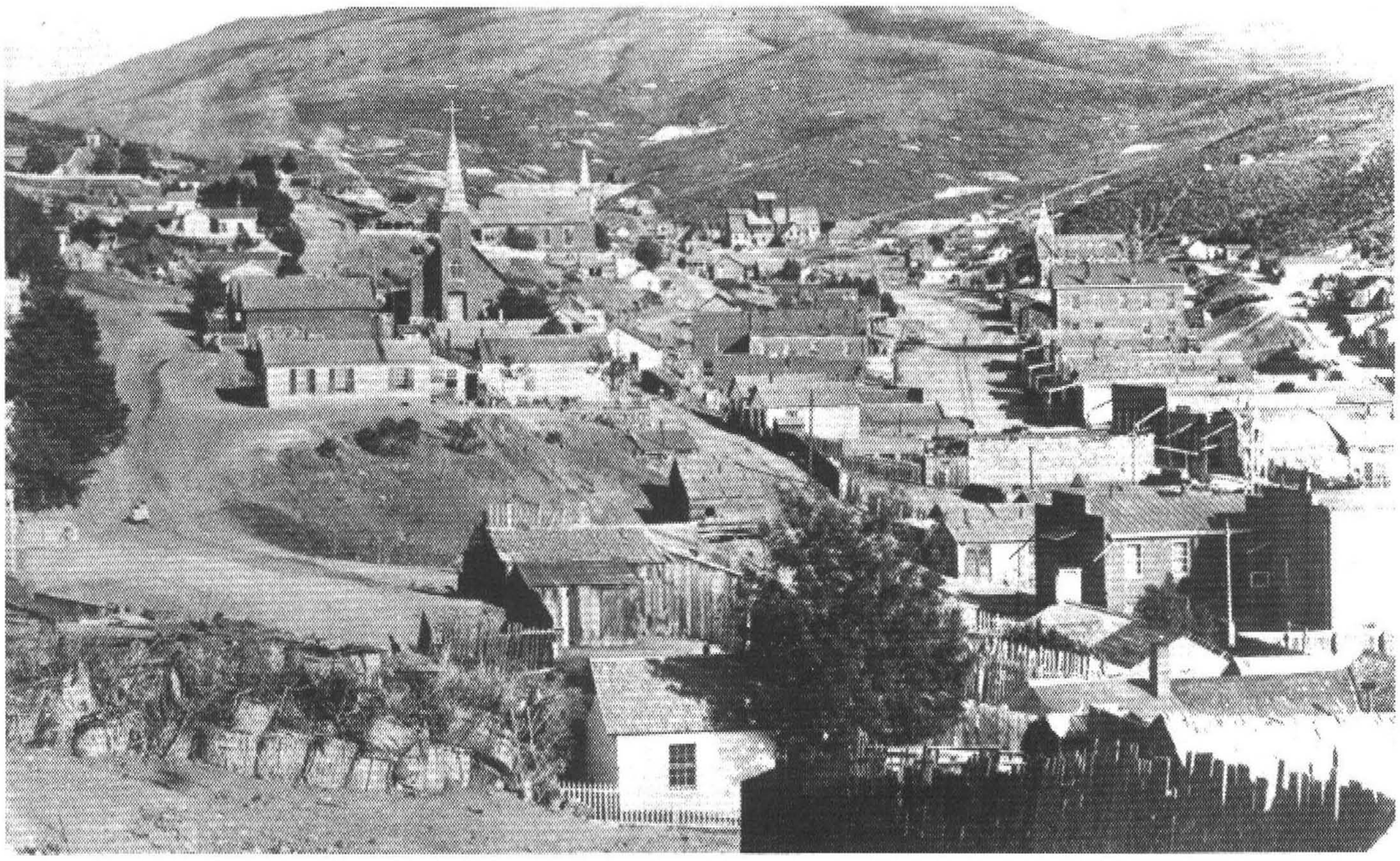
EUGENE J. MICHAL

The discovery of the Comstock Lode east of the Sierra in 1859 attracted a great rush of prospectors, miners, businessmen, financiers, con artists, and myriads of others eager to share in the riches the district would yield. But the euphoria of the early years quickly wore off, and as mining on the Comstock settled down to a routine for the prospectors and miners, many of them set out again, eastward, into the unexplored deserts, each in search of his own bonanza. So came about the discovery in 1862 of the silver ores in Pony Canyon, later to become Austin, Nevada, and in rapid succession a number of other discoveries in the same general region, known as the Reese River Mining District.

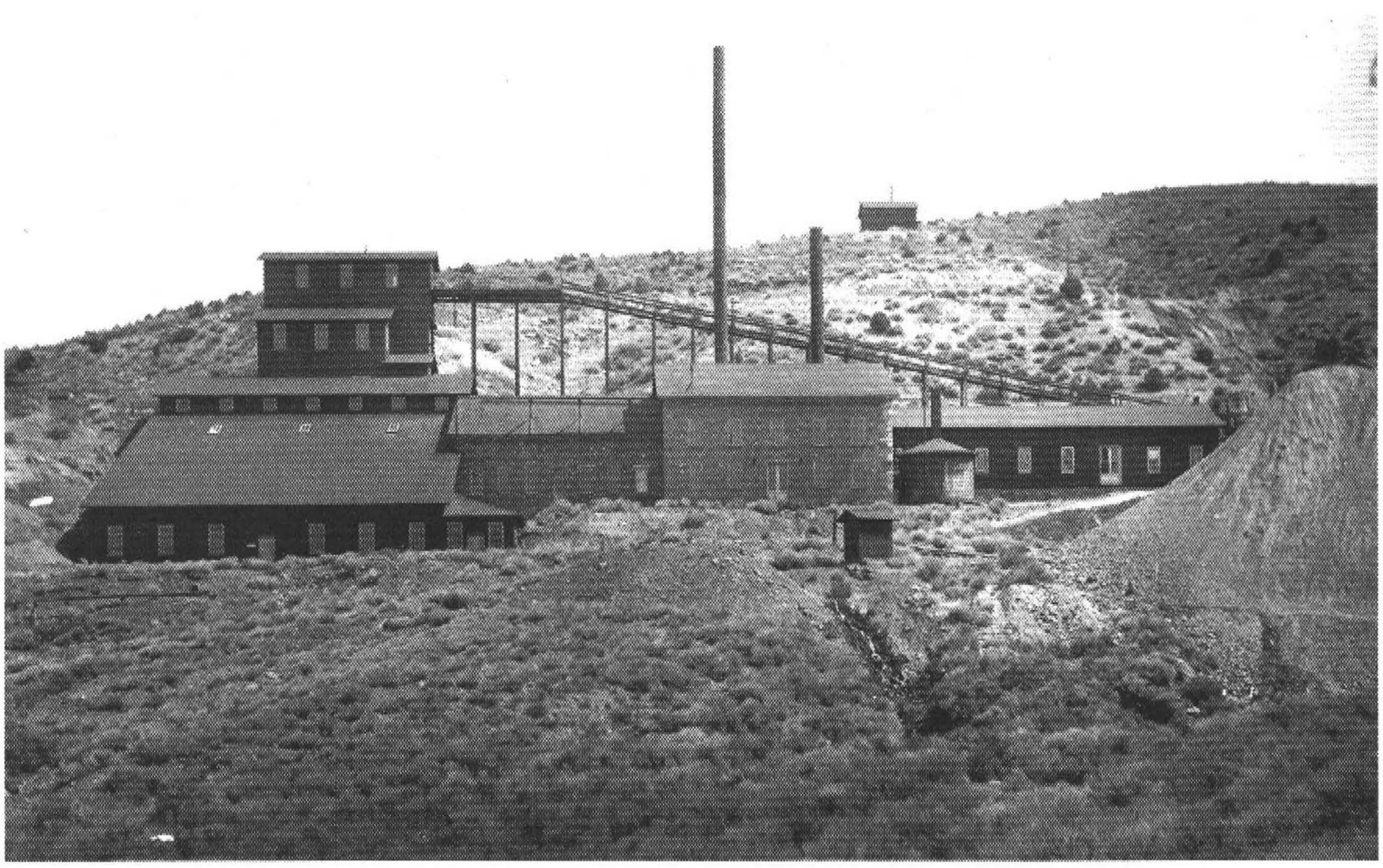
At first it appeared that the Austin ores, like those from the Comstock, could be treated by the pan amalgamation process—the Washoe Pan Process—as used on the Comstock Lode.[1] This thought was soon dispelled, however, for as the Austin ores were mined from increasingly deeper levels, the ore mineral changed from silver chloride to complex silver sulfide, and was assigned the term *rebellious ore*, as it failed to yield its silver to the pan amalgamation process. Eventually the losses of silver during the milling of these deeper ores became unacceptably high. Worse still, it was soon found that, even from the grass roots down, many of the ore deposits contained complex silver sulfide.

Keen scientific minds were needed to adapt these rebellious ores at Austin to the pan amalgamation process, as well as to develop the smelting processes required for the newly discovered silver-lead ores found at Eureka, Nevada. The men who would do this were being educated in the mining schools of Freiberg and Clausthal in Germany, and they were to play an important role in the development of metallurgical technology in the United States. One of them was Charles A. Stetefeldt, born Carl August Stetefeldt in Holtzhausen, Germany on September 28, 1838.[2]

The son of a Lutheran pastor who also ran a private boarding school, Stetefeldt was brought up in a traditional Protestant family. A precocious boy, young Carl soon showed an interest in the sciences, which he studied at the University of Göttingen, although his father had urged him to become a theologian. After his sophomore year at Göttingen, he entered the School of Mining at



Austin, Nevada in 1868. (*Nevada Historical Society*)



Austin Manhattan Co. Mill in 1897. (*Nevada Historical Society*)

Clausthal, and in 1862 he passed the Engineers Examination, receiving the highest degree in all branches of mining and metallurgy.

He was at once appointed to a government position examining various metallurgical works, and became the manager of a small copper plant in Bohemia. Soon he learned of the silver mining rush in the American West, and in 1863 immigrated to the United States, where he became an assistant to Professor Charles Joy of the Chemistry Department at Columbia University. Apparently he did not stay in that position long, for the university has no record of him in any official or unofficial capacity.[3]

Stetefeldt soon joined the firm of Justis Adelberg and Rossiter W. Raymond, a group of mining consultants with a rapidly expanding business and a shortage of trained experts. The firm had hired a number of experts from the German mining schools, including Anton Eilers and Otto Hahn, who later made significant contributions to the technology of lead smelting at Eureka, Nevada, and Leadville, Colorado. Stetefeldt was among the more respected of these German mining engineers, and was described by Rossiter Raymond as possessing "a knowledge of mathematics and chemistry beyond the usual equipment of a mining engineer or metallurgist, and at the same time an exceptionally wide scientific and literary as well as technical culture."[4]

The Austin Partnership

In 1865, the Adelberg and Raymond firm arranged a partnership between Charles Stetefeldt and John Boalt, a Freiberg graduate who had been a friend and classmate of Rossiter Raymond. Stetefeldt became the principal in this firm and, with Boalt, set up an assay office and consulting business in Austin, Nevada, in the same year.

The community of Austin had been established in 1862 at the site of a silver discovery a hundred and fifty miles east of Virginia City along the Pony Express route. Within a year a stage route had been established to Austin, and the community was experiencing the usual rush of prospectors and mining entrepreneurs.

A number of substantial silver or silver-lead discoveries were soon developed within a one-hundred-mile radius of Austin. The more prominent of these were Grantsville, discovered in 1863, Kingston in 1863, Mammoth-Ellsworth in 1863, Ophir in 1864, Belmont in 1865, Buckeye-La Plata in 1865, Eureka in 1865, Tybo in 1866, Northumberland in 1866, White Pine in 1868, Secret Canyon in 1869, and Mineral Hill in 1870.

The excitement of these discoveries, the development of a business community that "included three banks, thirty-three lawyers, twelve physicians and five clergymen," and the fact that "during 1865 the amount of treasure that passed through the office of Wells Fargo in Austin aggregated $6,000,000"[5] no doubt influenced the decision by Stetefeldt and Boalt to establish their consulting business in Austin.

John Boalt's interests, however, soon extended beyond mining into local civic matters, and in 1870 he became justice of the peace in Austin.[6] Boalt's father was a lawyer, and John later moved to San Francisco, where he practiced law himself, and handled the legal and patent affairs of what became the Stetefeldt Furnace Company, incorporated in 1872, C. E. Stetefeldt, president, and B. J. Burns, vice president and treasurer.[7]

Stetefeldt found ample opportunity to sell his services. The Oregon Mill in Austin had worked well for the first two years of its operation, patterned after the pan amalgamation process used on the Comstock Lode, but the favorable recoveries of silver were not to last. The initial success in milling was achieved because the near-surface ores first found in Austin were "chiefly chloride [of silver], bromide of silver being occasionally found. Below the water line only antimonial sulfuret ores exist, commonly called ruby silver."[8] It was the complex arsenical or antimonial sulfides present below the depth of the first occurrence of free water, known as the water table, that caused the amalgamation pan process to fail, and at Austin the water table was very shallow, in some cases only fifty feet below the surface.

It was known, however, that silver could be produced from complex silver sulfides by the Washoe Pan Process if they were first roasted in a furnace in the presence of common salt. The salt roasting generated chlorine gas, which converted the silver to silver chloride; this procedure was termed *chloridization roasting* in nineteenth century literature, or simply *chloridization*. With the advent of electrochemical methods of producing chlorine gas in the twentieth century, the term *chloridization* passed out of general metallurgical usage in favor of simply *chlorination*. Since the reactants and products are the same in both instances, the terms are used here interchangeably, *chloridization* being used only in deference to its use in earlier literature. Hence the reader should not infer that use there of the modern term indicates a different procedure.

Fairly large amounts of salt were required in the process—as much as 10 percent by weight of the ore. Fortunately, in terms of cost and convenience, an acceptable, though relatively impure, variety of salt was plentiful on the desert playas. Not so fortunate was the fact that the roasting process was costly in terms of manpower, fuel consumption, and capital investment. Furthermore, as the ores declined in grade from the original discoveries, the cost of wood in a desert area became a more critical factor, and cost-cutting measures were needed to prolong the economic life of the mines.

Stetefeldt's assay office became one of the more prominent in Austin. He assayed natural ores as well as silver bullion in arbitration between buyers and sellers, and also used his expertise to consult with the local mills on ore-processing problems. In 1866, he began studying the mineralogy of the so-called rebellious ores and made various explorations to other silver camps. On a trip to Belmont, he obtained a sample of a rare argentiferous antimonial sulfide, examined it, defined its chemistry, and brought it to scientific attention; and as a result, it was named in his honor Stetefeldtite,[9] which was later abridged to Stetefeldite.[10]

Mineral Hill, Eureka County, Nevada in 1902. (*Nevada Historical Society*)

Development of the Furnace

Austin ores required chlorination roasting, but it was not a well-developed technology in 1865. The conventional procedure was to place the ore and salt on the flat hearth of an oven-shaped "reverberatory" furnace and rake the ore back and forth by hand—rabble it—while the hot gases from the fire passed over the ore charge. This roasting process was slow and required extensive hand labor. Stetefeldt believed the procedure could be made more efficient, reproducible, and less labor intensive through use of a new type of furnace design. He had in mind a furnace consisting of a high shaft with alternate inwardly sloping terraced shelves on which the ore charge would slide down and move from side to side as the hot combustion gases rose up around the shelves and through the descending charge. Stetefeldt submitted a patent application based on this concept (the application bore the additional name of Partz) during the design phase of the furnace, and promptly ran into interference in the patent office with a similar proposal by a German, Moritz Gerstenhofer. Gerstenhofer had developed the sloping-shelf concept at Freiberg around 1864[11] and it had been used successfully in Mansfield, Prussia, to roast a crushed copper sulfide as an adjunct to the Zirvogel Process for recovering silver by selective sulfation.

At first the Americans claimed an equivalent antiquity for their idea, but any dispute was resolved by the purchase of the rights to both concepts by the American Metallurgical Company of New York, which combined the interests for commercialization. In 1867, a Gerstenhofer furnace was tested by Adolph Wolters at the Lyon Works of the Hill Smelter at Black Hawk, Colorado, for the roasting of auriferous pyrite. Known as the terrace furnace, it was touted as an epoch-making machine, equivalent in importance to the Bessemer Converter.[12] These high hopes were never realized. The furnace performed the roasting task too slowly. It was slow because its geometry did not provide for sufficiently rapid access of air (oxygen) to the charge, nor sufficient means for dissipation of the heat of reaction. These deficiencies apparently had been acceptable on high-value products where time could be sacrificed, as at Mansfield, but were not economical for low-grade ores, and the furnace at Black Hawk fell into disuse.

At the same time, Stetefeldt's concept failed its test at Austin because the salt fused on the shelves, and the sticky mass of ore and salt would not flow through the furnace. The disappointing results at both places, or possibly a judgment by the patent office that the concept was already in the public domain, caused American Metallurgical to abandon its patent prosecutions, for no such patent was issued in the name of either Gerstenhofer or Stetefeldt in the period from 1860 to 1886. It is surprising that Stetefeldt thought he had a patentable invention, as he was quoted as referring to his Austin furnace as a "Gerstenhofer furnace."[13] Presumably he believed that his innovation over Gerstenhofer was a chemical one—to add salt to the charge—rather than an improvement to the structural design of the furnace.

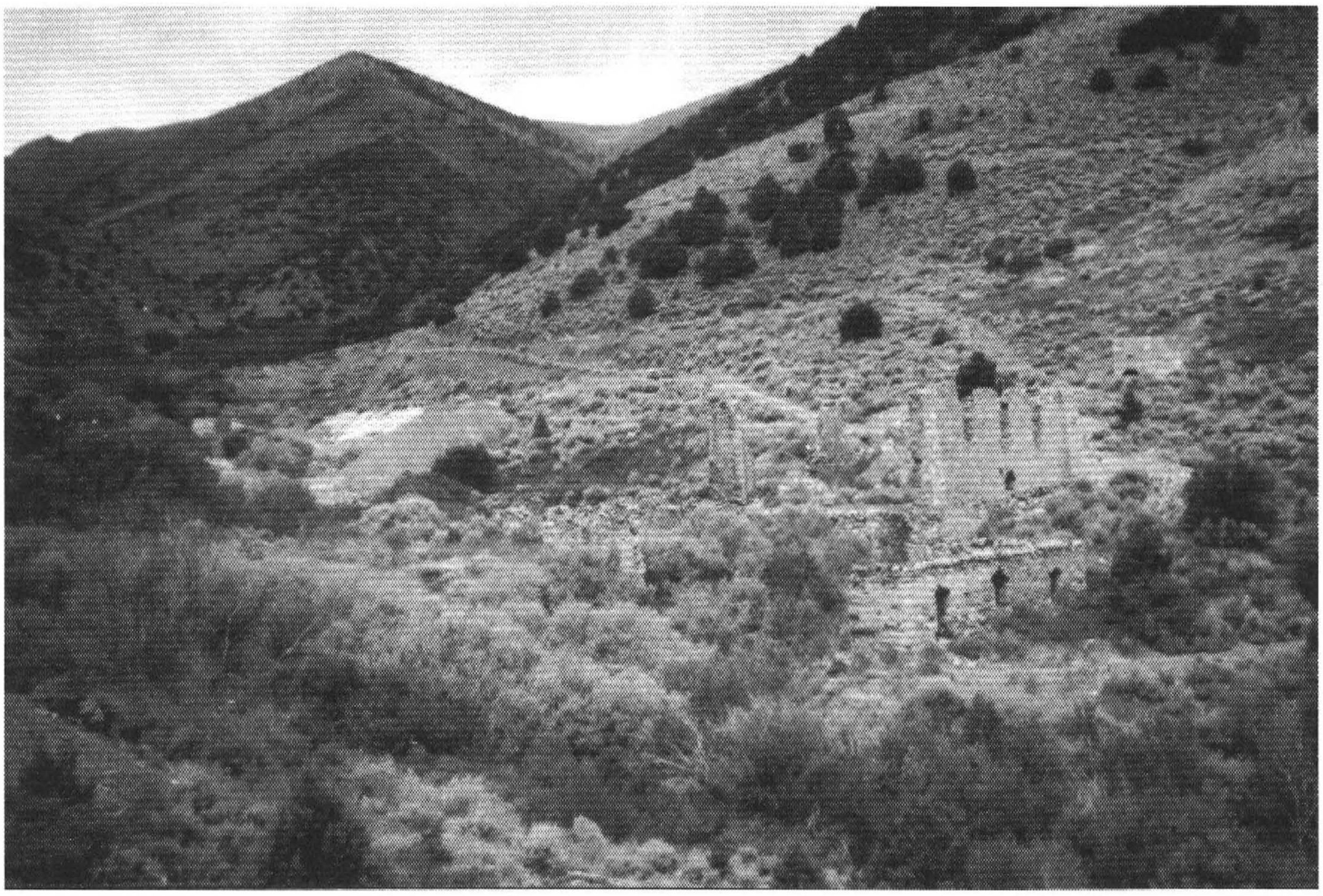
Stetefeldt did not give up completely on the sloping-furnace concept, and applied it to drying of ores rather than roasting. In 1881, he was issued a patent on "A Furnace for Drying Ores," which used the sloping-shelf idea, but in this case the flow of moist ore and hot gases were to move concurrently down the shelves rather than the gases rising and the ore descending.[14] This furnace could only treat ores that were already fairly dry, for if the ore was too moist it would ball up or stick to the shelves and not flow properly. As a result, Stetefeldt's dryer never found wide acceptance, although multiple units were in use at the Holden Mill in Aspen, Colorado, in 1891.[15] The sloping-shelf furnace concept, however, was used by others for other purposes, as for example, for the distillation of mercury from ores at Almaden, California, in a furnace built in 1880.[16]

The Austin setback did not dissuade Stetefeldt from the idea that silver ore could be roasted and chlorinated in a rising current of hot gases. He decided to test a furnace without shelves. In the spring of 1866, he convinced Messrs. Pritchard and Custer of the Midas Mill in Austin, owned by the New York and Reese River Company, also known as The Midas Silver Mining Company, to support the erection of an experimental furnace. Before they could build the furnace, however, the company went bankrupt. Undeterred, Stetefeldt decided to build a furnace at his own expense, if he could be assured of the assistance and cooperation of a local mill. James Bowstead, general agent of the Manhattan Silver Mining Company, owners of the largest silver mill in Austin, agreed to support his project. By December of 1866, Stetefeldt and his crew had constructed the new furnace at the Manhattan Mill and began experiments. Unfortunately, Bowstead died unexpectedly, and the new manager, Allen Curtis, withdrew support of the project.

Undaunted, Stetefeldt applied for a patent on his concept, even though its practicality was unproven, and continued to promote the idea. He was successful in receiving the desired patent on December 31, 1867.[17] The structural design of the furnace underwent many changes in later years, but the basic concept, that of dropping the ore and salt through a rising current of hot gases, remained inviolable, regardless of the physical arrangements or structure of the equipment. The basic patent was reissued to the Stetefeldt Furnace Company in 1878.

Stetefeldt's idea came to the attention of R. B. Canfield of the Twin River Mining Company, operating the Murphy Mine in Ophir Canyon on the eastern slope of the Toiyabe Mountains, forty miles south of Austin. Canfield, in view of his own problems with processing Ophir ore, saw the potential for success in the process and agreed to assist in its evaluation. Construction of a test furnace began at the Murphy Mine in June 1867. The experimental furnace consisted of a brick shaft twenty-two feet high, four feet square on the inside at the bottom, and three feet square on the outside at the top. Two fireplaces, one on each side of the furnace, sent hot combustion gases into the furnace through entry points three feet above the bottom.

The operating procedure was to preheat the furnace to a dull red heat, and then sift the ore, mixed with about 10 percent common salt, into the top of the furnace, allowing it to fall through the rising hot gases. As the ore fell downward through the hot gases, which were adjusted in the firing process to always have an excess of air (oxygen), the sulfide minerals burned to sulfur dioxide, and the sulfur dioxide reacted with the salt to produce chlorine gas. The chlorine gas converted the silver to silver chloride, which was recoverable by pan amalgamation. The chloridizing reaction continued for some hours in the



Ophir Canyon, Nye County, Nevada, the site of the first Stetefeldt furnace in 1999. The mine is to the left and the remains of the mill are on the right. There are no identifiable remains of the Stetefeldt furnace. (*Collection of the Author*)

roasted mass, which accumulated on the floor of the furnace. Although not appreciated at the time, the additional rest period of the hot ore and salt in the base of the furnace, or even in a heap scraped out to one side of the furnace, was found to be essential to complete the chlorination.

The flue gases, containing some fine ore dust, passed through another, smaller fireplace to complete the combustion of any silver sulfide which had become short-circuited. Finally, after passing through a settling chamber ten by eighteen feet in plan and ten feet high, the gases went to a draft chimney two feet in diameter and thirty feet high.[18]

After the break-in period at Ophir, a written communication received by the Belmont, Nevada newspaper, *The Silver Bend Reporter*, pronounced "that the Stetefeldt furnace is a great success. The silver is chloridized to 87 per cent, it readily amalgamates in the pans, it is neither burned nor full of lumps."[19]

The Ophir mine was not such a great success as the furnace. After producing ores valued at $100 to $200 per ton for two years, the veins pinched out, and in the spring of 1868 the company went into bankruptcy. Nevertheless, the Stetefeldt furnace had demonstrated a new and rapid ore-chlorination process. Figure 1 shows a 1999 view of the site in Ophir Canyon where the furnace was erected in 1867. A sign on State Highway 376 mentions the Stetefeldt furnace and directs motorists to the entrance to Ophir Canyon.

R. B. Canfield went on to Belmont, purchased the Arizona Mine, and erected and operated a new mill, also with a Stetefeldt furnace. The success of this furnace encouraged the erection of a second Stetefeldt furnace in the Belmont district by the Monitor Belmont Silver Mining Company. The remains of this second mill, including the furnace, are described in the appendix to this article.

M. Eissler, a metallurgist contemporary with Stetefeldt, and one who operated a Stetefeldt furnace at Mineral Hill, Nevada, in 1870[20] later claimed that the Stetefeldt furnace "may be considered in truth as one of the best innovations in silver metallurgy, "and further that "it was incredulous [*sic*] to believe that a complete chloridization of silver could be effected in the few seconds it takes for the shower of ore and salt to pass through an ascending flame."[21]

The success of the process can be attributed to the enormous energy potential of the reaction sequence:

$$Ag_2S + O_2 = 2Ag + SO_2$$

$$SO_2 + 2NaCl + O_2 = Na_2SO_4 + Cl_2$$

$$2Ag + Cl_2 = 2AgCl$$

The chemical potential of each of these reactions promotes a powerful shift of each to the right, and with the reactions strongly accelerated by the red-hot temperature of the interior of the Stetefeldt furnace.

The Belmont Mill in the early 1900s. View to the northwest. The Stetefeldt furnace is on the left. (*Nevada Historical Society*)

The Stetefeldt furnace at Belmont, Nevada, showing irregularity in brick construction. View toward the southeast. (*Collection of the Author*)

THE EUREKA ADVENTURE

In the spring of 1868, Stetefeldt took on another challenge. The Eureka Mining District was in its infancy. Rich silver ores had been discovered, but the silver was combined with lead in such a way that neither the conventional Washoe Pan Process nor the Reese River Process could liberate it. In addition, the ores contained substantial amounts of impurities—lime, silica, and iron oxides—and this made smelting with fluxes to remove the impurities the only alternative.

In America at that time the smelting of silver and lead ores was a crude art, having been done by hand in small oven-like furnaces, working with relatively high-grade ore. It was evident that hand smelting would be too slow and costly for the Eureka ores, and that they had to be smelted in large blast furnaces similar to those developed for iron smelting.

The Morris and Monroe Company acquired properties in Eureka and engaged Stetefeldt to design a furnace for smelting their ores.[22] In spite of his lack of experience in smelting he accepted the job, built a furnace, and in May of 1869 began smelting trials. Each of three attempts failed. Later analysis indicated several reasons for the failure: (1) the ore he was given did not have the correct ratios of lime, silica, and iron to give a fluid slag, i.e., that were not self-fluxing; (2) the furnace refractories were not of a proper composition and melted in the heat; and (3) the furnace air blast was not sufficient.

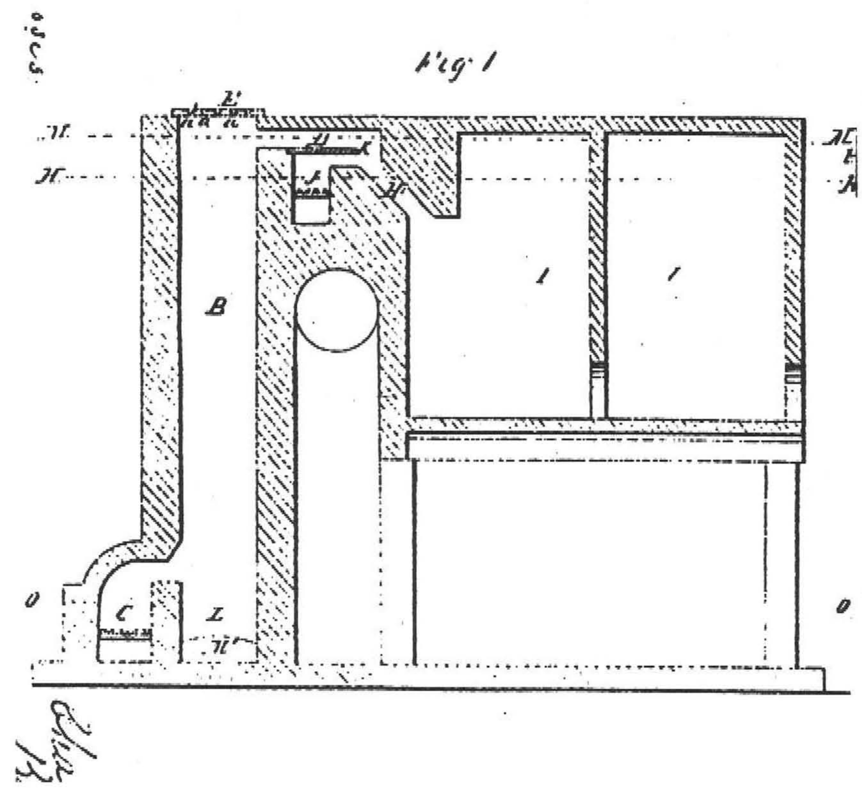
The Morris company and Stetefeldt abandoned the effort, and Major W. W. McCoy took over the furnace. He brought in experts from Wales experienced in smelting, and they solved the problems one by one. This made Eureka one of the premier lead-and-silver-producing districts of North America. Thirteen furnaces were operating in Eureka by 1876, with a combined daily capacity of 746 tons of ore. Lead-smelting technology developed at Eureka was taken to the Salt Lake Valley and to Leadville, Colorado, in the late 1870s. Stetefeldt later became a consultant for the furnace operators at Eureka, but in late 1869 he had other, more important interests.

The Reno Furnace

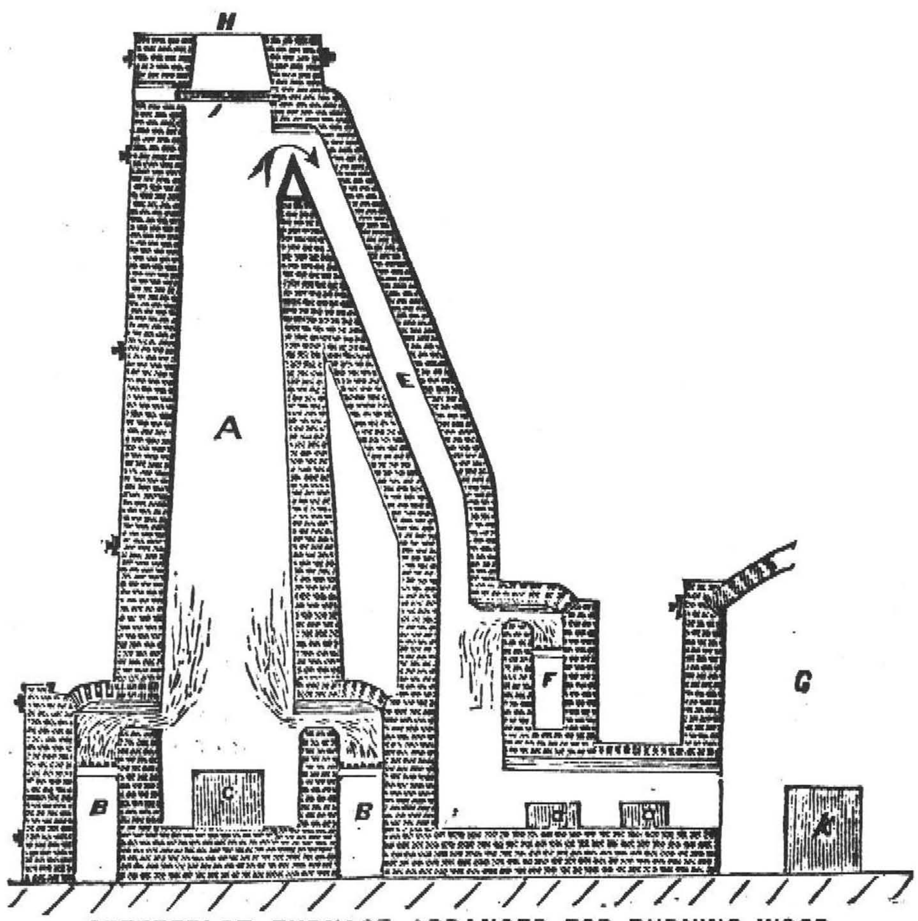
Stetefeldt became aware of a custom mill, the Auburn Mill, owned by a group of English investors, the Nevada Land and Mining Company, located near Reno.[23] The mill had a considerable potential for low-cost operation, as it was powered by water brought through the five-mile-long English Ditch from the Truckee River[24] and was near the recently completed transcontinental railroad. Stetefeldt thought that in this location he could use his chloridization process to demonstrate such an improved economy and efficiency of recovery of values from the Comstock ores, as well as from other northern Nevada ores, that it would attract a substantial business and have a potential for expansion.

He convinced the owners to install his furnace, and it proved successful. It was used on a variety of silver ores received from as far away as southern California, Utah, and British Columbia. Silver recoveries were usually in the range of 85 to 90 percent.[25] He had also noted that silver recoveries by the mills on the Comstock Lode were lower than those normally achieved with his furnace, and he arranged to obtain a lot of forty-eight tons of ore from the Gould and Curry Mine for testing in the Reno furnace in May of 1870. The assay value of the ore was $566 in silver and $211 in gold. The yield in bullion after treatment in the Stetefeldt furnace was 90 percent of the silver and 63 percent of the gold. He could not account for the disappearance of one third of the gold,[26] but as the result made it obvious that the Stetefeldt furnace was not applicable to processing of ores with substantial values in gold, its use was closed out on the Comstock ores.

Fifteen years later Stetefeldt was in the state of Vera Cruz, Mexico, studying problems in the amalgamation of the gold ores of Las Minas. Being an advocate of chloridization roasting, he tested the ores by this method and found to his great astonishment that under certain conditions of dead (complete) roasting, 65 to 85 percent of the gold was lost by volatilization, presumably as a



ORIGINAL PATENT (1867)



RENO, NEVADA (1869)

Stetefeldt Furnace Stuctural Designs. (*Collection of the Author, Nevada Historical Society*) chloride.[27] He published these results in 1885, but did nothing more on the subject. Investigation of the phenomenon by others from 1891 onward led to attempts to make chloride volatilization and condensation of gold and other metals a commercially viable process. These attempts were largely unsuccessful, with the exception of a plant at Cripple Creek, Colorado, that operated from 1900 to 1910.

Within a few years increases in freight rates and the drying up of the supply of high-grade custom ores slowed the Reno operations to the point of unprofitability. Further, A. D. Hodges, the plant manager, complained of "a board of trustees in London which tried to manage the mill from a distance and considered it an economy to spend nothing in the way of repairs and quicksilver."[28] He continued, "In a series of experiments to reduce salt consumption the mill was closed down and in the excitement attendant on the occasion the sheriff managed to get hold of the vessel holding the test liquor and by upsetting it managed to upset the experiment very effectually." No record has been found as to whether the plant ever operated thereafter.

The news of the success of Stetefeldt's furnace spread rapidly, and many mine operators plagued by poor silver recovery were signing up for the use of the process. Stetefeldt was a very busy promoter during the time of the operation of the Ophir and Reno furnaces, and he continued to troubleshoot various installations of his process for the next several years. In May 1870, the *Engineering and Mining Journal* reported: "We learn that Mr. Stetefeldt can hardly get assistants enough to supply the demand for superintendents of the construction of his furnaces in different localities in the State of Nevada."[29]

The Manhattan Mill

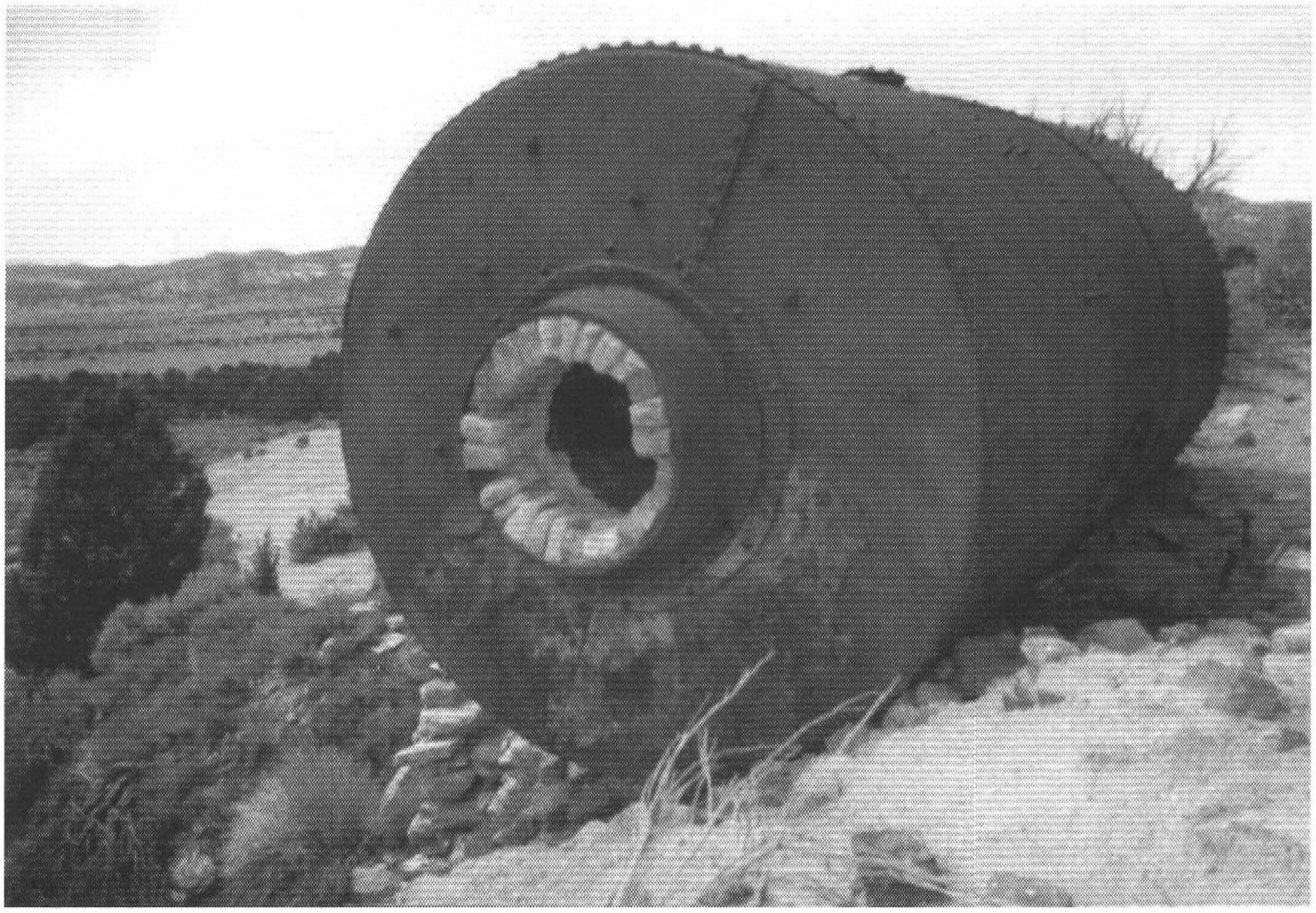
The Manhattan Silver Mining Company of Nevada, headquartered in Austin, owned one of seven silver mills that were operating in the Reese River Mining District in 1864. All of the mills used chloridizing roasting performed by hand in oven-type reverberatory furnaces. In 1865, the Manhattan company set out to dominate Austin milling by purchasing their principal competitor, the Oregon Mill. By 1868, most of the other mills in the district were idle and Manhattan's monopoly was essentially complete.[30] This was no guarantee of success, however, as declining ore grades in the district threatened the solvency of the corporation. With milling costs near a break-even point, the president of the corporation, H. Augustus Taylor, instructed Allen Curtis, the general manager, who had previously refused to support a Stetefeldt test, to look into the use of a Stetefeldt furnace as a means of reducing costs. Curtis sent an ore sample to be tested in the Reno furnace, and the results were favorable.

Negotiations with Stetefeldt for an exclusive license to use the process in the Reese River district culminated in the payment to Stetefeldt of $25,000 plus a royalty of $2 per ton for all ore treated.[31] This royalty was paid for many years thereafter. It seems reasonable to believe that the Manhattan company might have received the process rights free of charge or at a much-reduced rate had Curtis supported Stetefeldt in developing the furnace two years earlier.

The announcement of this agreement provoked a public outcry by miners and businessmen in Austin who alleged that it was in restraint of competition and that the local mining industry would be discouraged by the royalty charge.[32] Agent B. J. Burns of the Stetefeldt Furnace Company defended the charge, saying that the exclusive right was assessed "according to the extent and known value of each district," and that double the $25,000 charge paid by the Manhattan company would be "moderate for so rich a monopoly," while the royalty of $2 per ton "compares with a saving of $10 to $12 per ton in operating costs over reverberatory furnaces."[33] He was probably right, for roasting costs at the Manhattan Mill were cut in half, and prosperous operations were achieved by the mill for the remainder of the 1870s and early 1880s. By 1874, the royalty was reduced to 50 cents per ton for ores valued at less than $50 per ton, and to $1 per ton for ores valued higher than $50 per ton.[34] Unfortunately, ore reserves in the district declined by the mid 1880s, and the Manhattan corporation was bankrupt by 1887.

The Austin furnace, completed in 1870, was the first in which heating by producer gas, prepared in a separate gas generator, was substituted for wood fireplaces. The same type of system was installed at Belmont, Secret Canyon, and Mineral Hill, but problems soon appeared.[35] At Belmont, a destructive explosion occurred when the operator neglected to light the gas entering the furnace quickly enough after starting the generator, while at Secret Canyon an iron quicksilver bottle filled with water, used as a counterweight, fell into the gas generator and exploded. Fortunately no one was injured in either incident, but Stetefeldt returned to building furnaces with wood fireplaces. He later had another change of heart, for by 1896 he reported that four furnaces fired by gas were in operation, one at the Marsac Mill and two at the Ontario Mill, both in Park City, Utah, and one at the Holden Mill in Aspen.[36]

Chlorination prior to amalgamation had become a standard practice for treating the rebellious ores—those containing arsenic or antimony—and was known as the Reese River Process. Ernest Oberbillig gives an excellent summary of the mechanical equipment used in silver metallurgy up to 1900, including the construction and operation of the Stetefeldt furnace.[37] Contemporaneous with the perfection of the Stetefeldt furnace, other types of chlorination furnaces had been developed. The most important of these in the years from 1870 to 1900 were the Brueckner (often referred to as the Bruckner) and the White-Howell furnaces. The former was a short, large diameter, horizontal batch-process rotating cylinder with narrow entry and discharge ports at each end for charging and firing over a twenty-four-hour cycle. Examples of the Bruckner are shown and discussed in the appendix. The White-Howell was a long, narrow,

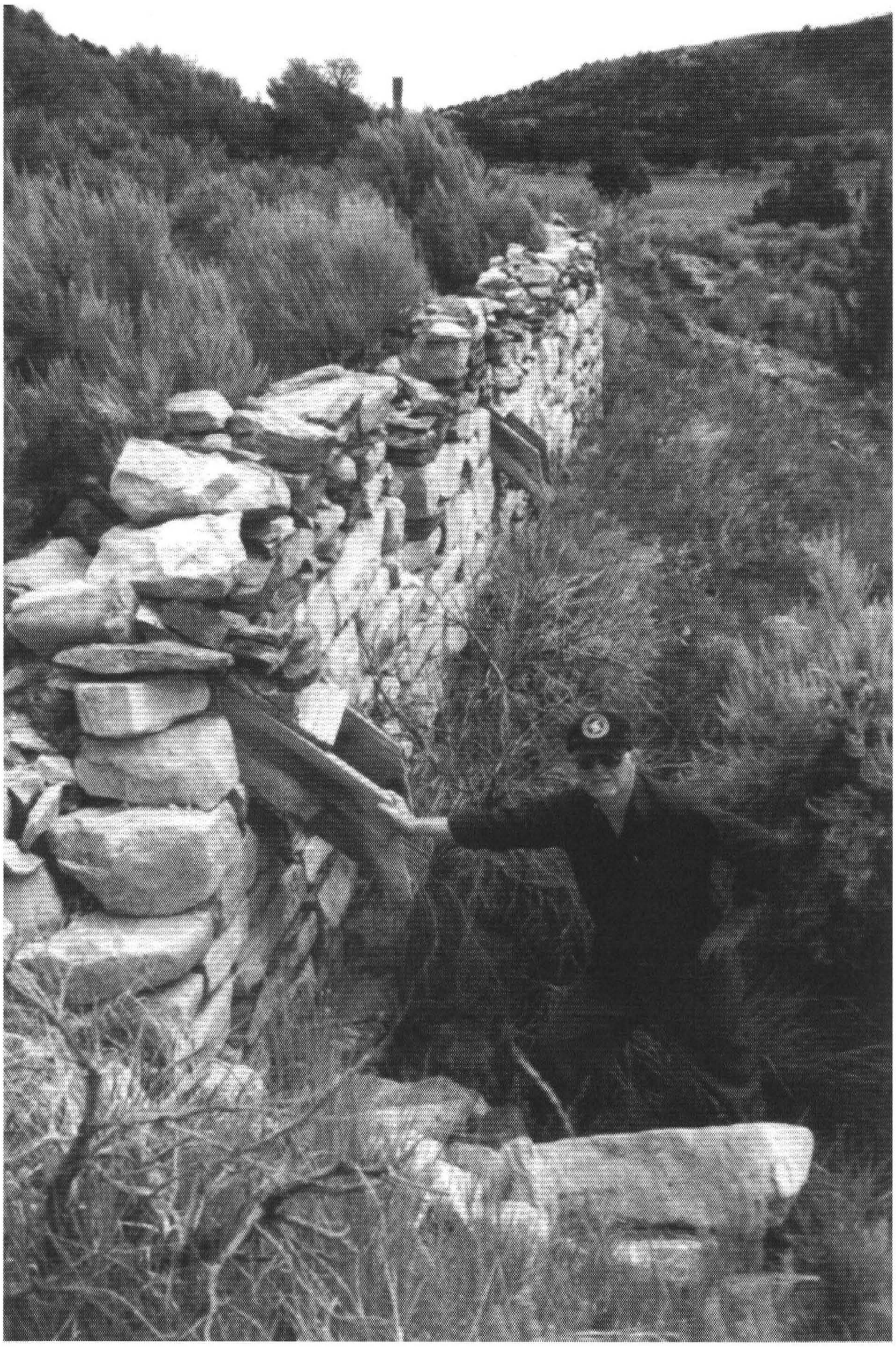


The Bruckner furnace for batch chlorination. Two of the furnaces can be seen on the extreme right in the photo on page 297. (*Collection of the Author*)

sloping-horizontal rotating cylinder which operated with a continuous feed and discharge.

The comparative efficiency and economy of these three types of furnace became the center of controversy and debate in the technical literature for more than twenty years. Any one of the three furnaces could perform chlorination; the problem was in quantitatively defining their relative merits. One advantage of the Stetefeldt furnace appears to be that the internal chamber of the furnace was uniformly hot and received a continuous flow of reactants, thereby generating a continuous supply of sulfur dioxide and chlorine, both of which were necessary to chlorinate the silver. Thus, conditions favorable for chlorination were always present, in contrast to the variable time, temperature, and atmospheric-composition zones found in the competing furnaces.

The drawback to the Stetefeldt furnace was that the twenty-five-foot high brick structure required considerable fuel to bring it up to the optimum temperature, and, once hot, it demanded continuous operation. Thus it was economical only on twenty-five tons or more of ore per day. If the mines could not supply that quantity of ore, the Bruckner furnace, which could handle from one to ten tons per batch, was preferred. The Stetefeldt furnace was a precursor in some respects to both the flash roaster and the fluidized bed reactor, both, in metallurgical parlance, " continuous well-stirred reactors," which were put into commercial use in the mid-twentieth century.



The feed chutes from the ore blending floor to the Stevenson Pans. (*Collection of the Author*)

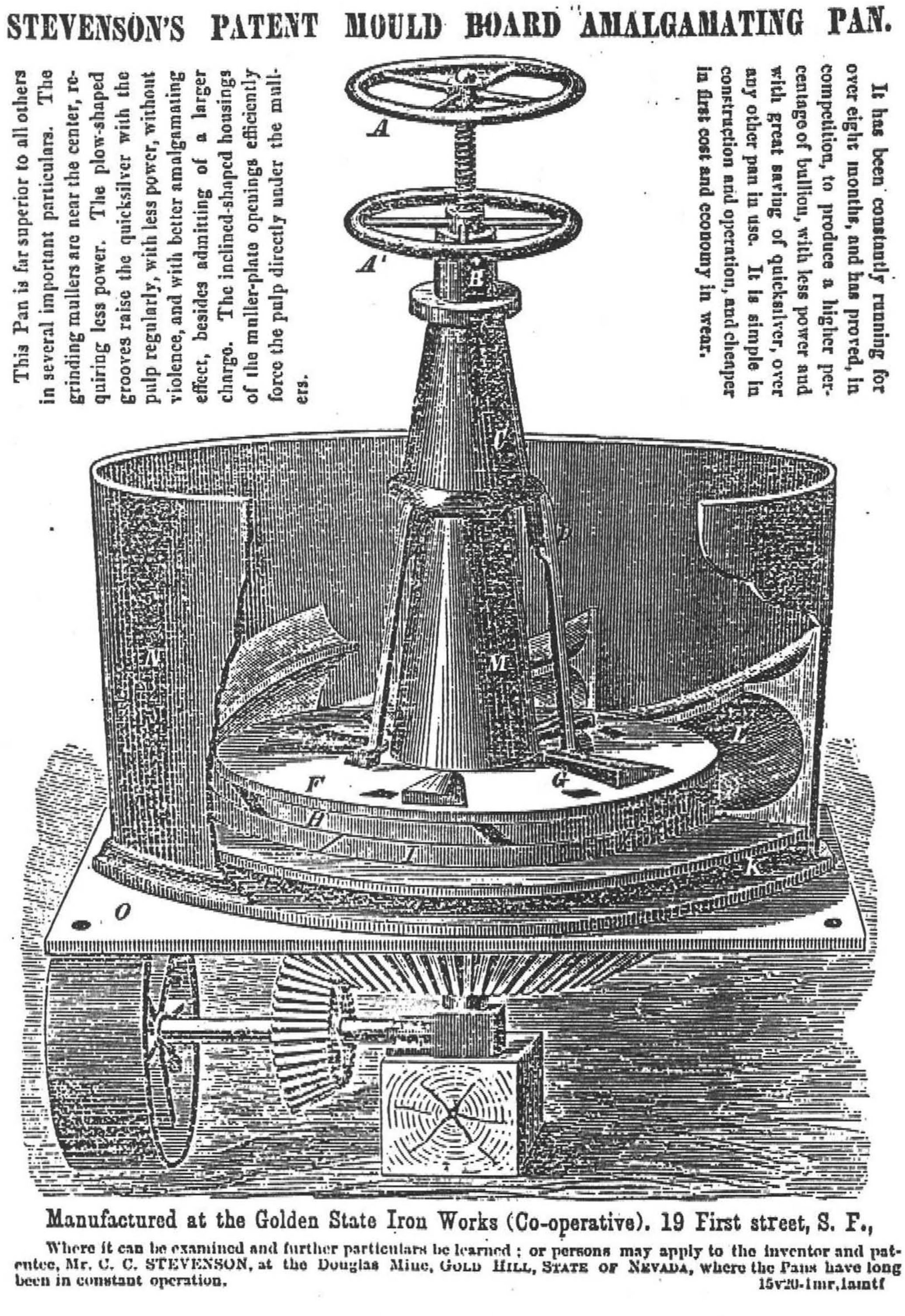
Stetefeldt was extremely defensive when his furnace was criticized, and often responded with masses of data and assertions that the data did not always confirm. He was demanding of his critics and, when denied data from operating mills, let the world know, e.g., "I applied to Mr. Reuger [of the Ontario Mill] for statistics—but he did not see fit to grant my request."[38] He could also be rather caustic in published comments, such as in response to published comments by Mr. Burthe, a graduate of the Ecôle des Mines in Paris, who had visited Austin, Nevada. Stetefeldt said of him, "Mr. Burthe published an article in *Annales des Mines* in which he criticizes the Stetefeldt furnace with such a lack of professional knowledge and fairness [that] I cannot allow him to go unrebuked for intentionally degrading an American invention." After explaining the inaccuracies in the article, he continued, "I never thought the latter [Mr. Burthe] would publish this barbarous method as a scientific experiment in a scientific journal" and "use mathematical sleight of hand [to engage in] wholesale condemnation of the principle on which the furnace is based."[39]

Stetefeldt also challenged one of his fellow metallurgists by asserting that "[Ottokar Hoffman was] never an enthusiastic admirer of the Stetefeldt furnace [and] would surely have published facts detrimental to its reputation if results had warranted him in so doing."[40]

In his willingness to dispute his critics, he became one of the primary contributors to the contemporary technical literature on the metallurgy of silver. He also found it necessary to defend his patent from infringement by others. In the first instance, John P. Airy built a copy of the Stetefeldt furnace at his mill in Georgetown, Colorado, and was challenged by Stetefeldt for patent infringement. A compromise was effected, and "the interests of the two parties will henceforth be identical. The furnace will be enlarged and improved without the troublesome limitations of the threatened interference of patent rights."[41] Unfortunately, the process did not work well on the Georgetown silver ores, as they contained an impurity of zinc sulfide which did not roast completely in the Stetefeldt furnace. Subsequent leaching of the roasted ore caused a reversion of part of the soluble silver to the sulfide form, representing a silver loss.

In a second instance, the Aiken Furnace Company was taken to court and their furnace was, according to Stetefeldt, "judged to be a bold infringement of the patents of the Stetefeldt Furnace Company, as demonstrated in the U. S. Circuit Court for the District of Nevada."[42] The Aiken company subsequently took a license from Stetefeldt.

By 1873, the Stetefeldt furnace, as part of a complete silver mill, was being manufactured and marketed by H. J. Booth and Company of San Francisco, "the largest builder of mills and milling machinery on the Pacific Coast."[43] By mid-1874, Stetefeldt reported that twenty of his furnaces had been built: fourteen in Nevada, three in Utah, one in Colorado, one in Mexico, and one in Australia, and he had under construction a plant at Panamint, California.[44]



The Stevenson Pans. (*The Mining and Scientific Press,* ca. 1870)

HYPOSULFITE LEACHING OF SILVER

In 1848, John Percy of London had suggested the use of sodium or calcium hyposulfite as a solvent for the chloride of silver after a chloridizing roast of a sulfide ore. This "wet" process was first put into commercial use in Bohemia by Von Patera in 1856 and became known as the Patera Process. It did not gain wide acceptance for several reasons: It did not recover the metallic silver present in many ores, insufficient roasting led to poor recoveries, and the presence of zinc sulfide in an ore caused the reversion of silver to the insoluble form. Nevertheless, the ores at Park City being roasted in a Stetefeldt furnace seemed to respond well to the process, and it was installed at the Ontario Mill. Mr. E. H.

Russell, a metallurgist at the mill, discovered sometime prior to 1884 that the addition of copper sulfate to the hyposulfite solution vastly improved its dissolving action even on silver ores that had been imperfectly chloridized.

When Stetefeldt heard about this through his association with the Ontario Silver Mining Company, he persuaded the manager, Mr. R. C. Chambers, to support further experiments by Russell on a wide variety of ores. Based on Russell's results, Stetefeldt devoted much time in the mid-1880s to defining the applicability of the process. He described his conclusions in 1884 in a seventy-page technical dissertation,[45] and in 1888 published a book not only describing the chemistry of the process, but presenting an engineering design and layout for a process plant.[46] Stetefeldt and Russell subsequently collaborated in the erection of at least ten mills in the late 1880s and early 1890s using the combined technology, under the aegis of the Russell Process Company of New York.[47]

One of Stetefeldt's antagonists, Ottokar Hoffman, declared—in what one can sense was a charitably worded understatement—that "the Russell process, which was so elaborately and well written up—has not proved a success." He went on to explain the reasons for its failure and subsequent abandonment at Sombrerete, Mexico, where he was employed in a "works built by Stetefeldt and Russell."[48] Stetefeldt was right when he said that Hoffman "was never an admirer of the Stetefeldt furnace," and apparently Hoffman didn't think much of Russell either.

Oxygen in Hydrometallurgy

To his considerable credit Stetefeldt recognized a factor that later would be seen as a crucial element of hydrometallurgical processes. He noted that "the precious metals have to become oxidized, the oxygen being derived from the air absorbed by the solution."[49] He had dusted off the outcrop of a bonanza of technology that would be mined in the twentieth century under the heading of "redox potential." Yet neither he nor anyone else went on to make the correlation that the copper in the solution facilitated the oxygen transfer into the solution and made the process viable. Neither did they extrapolate that conclusion to explaining why roasted copper and iron sulfates (the *magistral* of early Spanish literature) had made the 300-year-old Patio Process used in Mexico viable, or how it improved the Washoe Pan or Reese River processes. In fact, none of the leading chemists or metallurgists of the day wrote oxygen into their equations describing the dissolution of silver from the rebellious ores, although it was an essential element. For this they can be excused, as the science of chemistry was in its infancy, and the noted Swedish chemist S. A. Arrhenius was just beginning to develop the theory of ionic dissociation, which would be essential to explain aqueous oxidation and many other phenomena of chemistry and metallurgy.

Eleven half-buried wooden barrels in a straight line, probably amalgam settlers. (*Collection of the Author*)

CONCLUSION

Charles Stetefeldt was the recipient of five United States patents on metallurgical processes or engineering devices and the author of twenty-one papers published in the annals of the American Institute of Mining Engineers and other scientific writings. Stetefeldt's inventions and his persistence in their engineering application gave life to many mines and mining districts which otherwise may never have thrived. His analysis of the chemistry of silver metallurgy was more extensive and more widely published than that of any other of his contemporaries and inspired many others to take up the search for new silver recovery processes. His scientific curiosity in the field of geology and mineralogy also shone brightly, as evidenced by his discovery of a new silver mineral that now bears his name. He was aggressive, and stimulated many spirited discussions among his colleagues on the topics of engineering and chemistry.

Not much is published about his personal life. The sale of the exclusive rights to his process in Austin in 1870 provided him the means to return to Germany, but his father had died and he found no inducement to remain there. He returned to San Francisco, the site of his corporate headquarters, in 1872 where he married and where he resided while legal defenses of his furnace patent were in progress. In 1881, he joined the American Institute of Mining

Engineers; he was elected a vice-president of the institute in 1888, he was re-elected to that post in 1895 and held that position until his death. Although he had moved to New York City in 1882, he returned in 1889 to Oakland, California, where he spent his remaining years.

His accomplishments spanned a period of twenty-five years and were eloquently described in the technical literature. The panic of 1892-93 and the demonetization of silver were severe blows to the silver mining industry. The price dropped from ninety-four cents an ounce in 1889 to sixty-four cents in 1893 and ultimately to fifty-nine cents in 1898. In the face of this disappointment, and in the grasp of an incurable ailment of the heart, Stetefeldt made his final contribution to the literature on silver metallurgy in a spirited 1895 defense of the performance of the Stetefeldt furnace at the Holden Mill in Aspen, even though by that time the mill had been closed for more than a year.[50] He died on March 17, 1896, at the age of fifty-seven. His wife had died some years earlier. They had no children.

Appendix: The Stetefeldt Furnace at Belmont

The Monitor and Independence Millsite patented claim at Belmont, Nevada, holds the remains of the Monitor Belmont silver mill, including what is probably the last remaining structure of a Stetefeldt chlorination-roasting furnace.

R. B. Canfield, former manager of the Twin River Mining Company at Ophir Canyon, which failed in bankruptcy in 1868 because of lack of ore, came to Belmont in early 1870. There, he promptly joined with one Vollmer in purchasing the Arizona Mine. This mine held six hundred feet on the El Dorado vein and had been owned and worked by a Mexican, Antonio Bergues, using the arrastra amalgamation process. The arrastra milling, done in a circular stone basin, gave a poor recovery of silver, so Canfield arranged to use the steel-pan-process Buel Mill in the town of Belmont to process the Arizona ore.[51] However, the pan mill also gave a poor recovery of silver, and he soon realized that he needed a more efficient mill.

In August of 1870, he purchased the mill of the bankrupt Northumberland Mining Company,[52] located in the Toquima Range thirty miles north of Belmont. He brought the mill to Belmont, added to it an "improved" Stetefeldt furnace, and became the sole proprietor of the new Canfield Mill.[53] By October he was processing ore from the Transylvania mine of the Belmont Silver Mining Company, ore from the El Dorado Consolidated Mining Company, and ore from his own Arizona claim. In December of 1871 Canfield leased the mill to the El Dorado South Company to process their ore,[54] which was increasing in volume and had been going to Austin for treatment. In mid-1872, after encountering high-grade ore, the El Dorado South Company took over complete ownership of the mill.

Newspaper reports indicated that by January of 1873 El Dorado South had completed a twenty-stamp mill that included a Stetefeldt furnace. This most likely represented a doubling of the original ten-stamp Canfield Mill. This mill was said to be located four hundred yards below the hoisting works of the El Dorado South mine.[55] The foundations of this mill and extensive tailings deposits are clearly evident today. Bertrand Couch reported that it produced more than one million dollars in silver.[56] There is no sign of the prior Stetefeldt furnace.

In 1872, the Monitor Belmont Silver Mining Company also encountered high-grade ore and decided that a new mill was needed.[57] That mill was completed in March of 1873, operating with twenty stamps, dry crushing, dust chambers, a Stetefeldt chlorination furnace, six Stevenson amalgamating pans, four settlers of twenty-five hundred pounds capacity each, and two thirty-horsepower steam engines to power the mill. The mill was said to be located in the canyon, three quarters of a mile below town.[58] This clearly fits the description of the site of the fifty-foot-high Stetefeldt furnace structure located on the present-day Monitor and Independence Millsite patented claim.

The photograph on page 297 shows the Monitor-Belmont Mill in the early 1900s. The photograph on page 298 is of the Belmont furnace structure as it existed in 1999. The sketches on page 300 show the furnace sketch embodied in the original Stetefeldt patent and the structural design represented by the Reno furnace built in 1869. The structural design remained relatively unchanged after 1869.

The structure of the existing Belmont furnace can be compared with the Reno furnace and other designs as follows: The original patent proposed a furnace twenty-five feet high and three feet square internally. The Reno furnace, built in 1869, was twenty-eight feet high and four feet, six inches square externally, at the base. The Belmont furnace, built in 1873, was fifty feet high and six feet square, externally, at the base, and two feet square internally. The furnace at the Marsac Mill at Park City, Utah, and the furnace at the Holden Mill at Aspen, Colorado, which Stetefeldt himself said in 1894 were of the latest design,[59] were of dimensions identical to the existing Belmont furnace.

The Belmont furnace shows clearly the characteristic double firing chambers at the base and the large rake-out opening. Above, at the twelve-foot level, is the third firing chamber for the fine dust, opening directly into the gas flue that leads to the dust chamber and the draft stack. This suggests that the Belmont furnace was the culmination of the major structural design of the furnace and occurred prior to 1872. Minor changes appeared in later furnaces, but were refinements to the internal structure of the gas and dust flow conduits.

Unfortunately, the dust chambers and draft stack of the Belmont furnace are missing. Brickwork in the dust flue is partially replaced by brick and mortar of a distinctly different color, installed with workmanship not equaling that of the original structure (evident in the photograph on page 298). This repair was probably required after an accident that can be described as follows: Stetefeldt's original furnaces were fired with wood, but he recognized the advantages of firing with gas (to eliminate ash and soot from the treated ore), and as early as 1870 converted the Austin furnace to the use of producer gas made from charcoal, burned exterior to the furnace. The Belmont furnace was similarly built to use producer gas, and did so for a period of time. However, as Stetefeldt relates, "such complicated apparatus was not safe in the hands of the average 'muscular amalgamator,'" and further "at Belmont an explosion destroyed the arches of the dust chambers, the foreman of the mill having neglected to light the gas after starting the generator."[60] This explains the necessity to rebuild the furnace, which, we may conclude from its appearance, was never completed. This corresponds with the fact that the ore reserves at Belmont were largely exhausted by 1874, and milling slowed to a very low pace, which was not consistent with economy of operation of the Stetefeldt furnace.

Also at the site are two steel brick-lined Bruckner batch-roasting furnaces about five feet in diameter and ten feet long lying on the ground. One of these is shown on page 303. There is some indication of a foundation for these machines, but no drive mechanism. The drive gears were probably sold for scrap, along with the iron stamp mill, during World War II, if not earlier. These furnaces were promoted by the manufacturer to do essentially the same job as the Stetefeldt furnace, but on small lots of ore, not more than a few tons at a time. If they were used, it was probably either before the Stetefeldt furnace was built or as a substitute after the aforementioned explosion. Since ore reserves were largely depleted by 1874, it appears that the use of the Stetefeldt furnace was abandoned when the tonnage of ore produced was too small to be economically treated in that design, and the Bruckner furnaces were substituted.

In addition to the brick furnace structure, the Monitor and Independence Millsite contains the foundations of the stamp mill; the ore chutes shown on page 304, from which crushed ore was delivered to the Stevenson pans which were ground, amalgamated with mercury, and put into eleven half-buried open-top wooden barrels (shown on page 308), which were probably amalgam settlers positioned below the Stevenson pans.

The present owner (1999) is heir to the Monitor and Independence Millsite patented claim, the family having maintained continuous possession since 1934, but has had no active interest in maintaining the facility other than admonishing the United States Army Air Force in the 1940s to quit using the furnace structure for aerial target practice. Evidence of bullet holes in the brick can still be seen. The owner is willing to entertain proposals for the preservation of this site.[61]

NOTES

[1]The Washoe Process consisted of grinding the ore in a steel pan in the presence of common salt, mercury, and other chemicals, whereby the silver was converted to a chloride, and the silver chloride was reduced by the mercury to metallic silver. The metallic silver combined with the mercury to form an amalgam, and the amalgam was recovered from the pan and retorted to drive off the mercury. The process is described in Eliot Lord's *Comstock Mining and Miners*, (1883; reprint Berkeley, Calif: Howell-North, 1959).

[2]Rossiter A. Raymond, "Biographical Note of Charles A. Stetefeldt," *Transactions of the American Institute of Mining Engineers* (hereafter cited as *Trans. AIME*), 26(1896), 597.

[3]Rhea E. Pliakas, Director of Archives, Columbia University, private communication, 1 March 1999.

[4]Raymond, "Biographical Note," 597.

[5]Myron Angel, ed., *History of Nevada* (1881; reprint Berkeley: Howell-North Publishing Co., 1958), 468.

[6]*Reese River Reveille* (Austin, Nevada), (2 September 1870).

[7]Editors, *Mining and Scientific Press*, 25 (7 December 1872), 364.

[8]Angel, *History of Nevada*, 468. Technically, the definition given in Angel's Nevada history, of ruby silver as antimonial silver, is not correct; ruby silver is an arsenical silver sulfide, not antimonial.

[9]*Silver Bend Reporter* (Belmont, Nevada), (13 April 1867).

[10]David Von Bargen, "Nevada Gold, Silver, and Copper Deposits," *Rocks and Minerals*, 74 (November-December 1999), 414. Also, private communication to the author, January 2000. Von Bargen provides the following clarifications: Stetefeldite was first listed in Edward S. Dana's *System of Mineralogy* (6th edition) in 1892. While the original composition showed silver, antimony, copper, iron, and sulfur, more detailed studies by Mason and Vitaliano (*Mineralogical Magazine*, 30 (1953), 105) indicated that it was a hydrate containing only silver and antimony. Von Bargen simplified the chemistry to $Ag_2Sb_2(O,OH)_7$. He adds that it was the first " type mineral" (bearing the standard properties with which subsequent discoveries should be compared) described from Nevada.

[11]James E. Fell, *Ores to Metals: The Rocky Mountains' Smelting Industry* (Lincoln: University of Nebraska Press, 1979), 29.

[12]"Colorado Ores: The Terrace Furnace," *The American Journal of Mining* [predecessor to the *Engineering and Mining Journal*], 4, (28 December 1867), 406; 5, (4 January 1868), 8.

[13]"The Stetefeldt Furnace at Reno, Nevada," *Mining and Scientific Press*, 19 (11 December 1869), 377.

[14]United States Patent no. 238,455, 1 March 1889.

[15]Willard S. Morse, " The Lixiviation of Silver Ores by the Russell Process at Aspen, Colorado," *Trans. AIME*, 25 (1895), 137

[16]William Forstner, "Quicksilver Resources of California: The Huttner-Scott Furnace," *California State Mining Bureau, Bulletin No. 27*, San Francisco, Calif. (1908), 220.

[17]United States Patent no. 72,931, 31 December 1867.

[18]*Silver Bend Reporter* (4 April 1868).

[19]*Ibid.*, (7 March 1868).

[20]"The Mineral Hill District," *Engineering and Mining Journal*, 12 (21 November 1871), 332.

[21]M. Eissler, *Metallurgy of Silver*, 3d. Ed. (New York: D. Van Nostrand, 1896), 179.

[22]Angel, *History of Nevada*, 431.

[23]C. A. Stetefeldt, "The Stetefeldt Furnace,"*Mining and Scientific Press*, 19 (11 December 1869), 377; "The Auburn Mill, Reno, Nevada,"21, (24 September 1870), 218. Also see "The Modification of the Stetefeldt Furnace,"21 (5 December 1870), 433; 22 (22 April 1871), 248.

[24]Angel, *History of Nevada*, 634.

[25]A. D. Hodges, " Experience with the Stetefeldt Furnace," Rossiter A. Raymond, *Mines and Mining West of the Rocky Mountains* (1876), 411.

[26]C. A. Stetefeldt, "Russell's Improved Process for Lixivation of Silver Ores," *Trans. AIME*, 13

(1884), 82.

[27]C. A. Stetefeldt, " The Amalgamation of Gold Ores and the Loss of Gold in Chloridizing Roasting," *Trans. AIME*, 14 (1885), 336.

[28]Hodges, "Experience with the Stetefeldt Furnace,"82.

[29]"The Stetefeldt Furnace," *Engineering and Mining Journal*, 9 (31 May 1870), 345.

[30]Donald R. Abbe, *Austin and the Reese River Mining District, Nevada' s Forgotten Frontier* (Reno: University of Nevada Press, 1985).

[31]"The Stetefeldt Furnace," *Mining and Scientific Press*, 21: 2 (October 1870), 234.

[32]*Reese River Reveille* (18 January 1870).

[33]"The Stetefeldt Furnace," *Mining and Scientific Press*, 234.

[34]C. A. Stetefeldt, "Some Remarks about the Stetefeldt Furnace,"*Engineering and Mining Journal*, 18 (1 August 1874), 67.

[35]C. A. Stetefeldt, "The Stetefeldt Furnace," *Trans. AIME*, 24 (1894), 3.

[36]C. A. Stetefeldt, "Communication to the Secretary of AIME: Reply to Mr. Douglas," "Summary of American Improvements and Inventions," *Trans. AIME*, 26 (1896), 659.

[37]Ernest Oberbillig, "Development of the Washoe and Reese River Silver Processes," *Nevada Historical Society Quarterly*, 10 (Summer 1967), 5-43.

[38]C. A. Stetefeldt, "Reply to the Morse Paper," *Trans. AIME*, 25 (1895), 995.

[39]"A French Engineer on the Stetefeldt Furnace," *Engineering and Mining Journal*, 19 (27 February 1875), 131.

[40]Stetefeldt, "Reply to Morse Paper," 995.

[41]"Compromise on Airy Furnace," *Engineering and Mining Journal*, 14 (5 November 1872), 297.

[42]Stetefeldt, "Some Remarks," *Engineering and Mining Journal*, 18 (1 August 1874), 67.

[43]Advertisement, Booth and Co, *Engineering and Mining Journal* 15 (29 April 1873), 257.

[44]*Ibid.;* Stetefeldt, "Some Remarks,"*Engineering and Mining Journal* 15; 18 (1 August 1874), 67; 18 (10 October 1874), 242.

[45]Stetefeldt, "Russell's Improved Process,"82.

[46]C. A. Stetefeldt, *Lixiviation of Silver Ores with Hyposulfite Solutions, with Special Reference to the Russell Process*, (New York: privately printed, Scientific Publishing Co. [press of Tuttle, Morehouse, and Taylor, New Haven], 1888).

[47]C. A. Stetefeldt, *Lixiviation of Silver Ores with Hyposulfite Solutions*, 2d ed. (New Haven: Tuttle, Morehouse, and Taylor, 1895).

[48]Ottokar Hoffman, *The Hydrometallurgy of Silver, with Special Reference to Chloridizing Roasting of Silver Ores and the Extraction of Silver by Hyposulfite Solution* (New York: Hill Publishing Co., 1907).

[49]Stetefeldt, *Lixiviation of Silver Ores (1888).*

[50]Stetefeldt, "Communication to the Secretary," 995.

[51]*Mining and Scientific Press*, 21 (30 July 1870), 77

[52]*Ibid.*, 21 (27 August 1870), 141.

[53]*Ibid.*, 23 (30 September 1871), 195.

[54]*Ibid.*, 23 (16 December 1871), 372.

[55]*Reese River Reveille* (4 December 1873).

[56]Bertrand F. Couch, "Nevada's Metal and Mineral Production," *Nevada State Bureau of Mines*, 37: 4 (1943).

[57]*Mining and Scientific Press*, 24 (4 April 1872), 293.

[58]*Reese River Reveille* (4 December 1873).

[59]Stetefeldt, "Stetefeldt Furnace," 4.

[60]*Ibid.*

[61]Owner of the furnace to the author, private communication, 1999.

The Saga Continues
Implementing the Negotiated Settlement

LEAH J. WILDS AND RICHARD ACTON

INTRODUCTION

In 1990, Congress passed Public Law no. 101–618, which contained the Truckee-Carson-Pyramid Lake Water Rights Settlement Act. Many observers closely followed the negotiations that led to its passage. Some believed that the act would prove indicative of a new direction in water policy in the American West, with significant consequences for all stakeholders.[1] Policy scholars speculated about the degree to which these negotiations might represent a challenge to the traditional approach to the making of water policy in the West, one that involved an entrenched set of stakeholders who made most of the water allocation and use decisions, to the exclusion of newer and competing interests.[2] Many scholars discuss these stakeholders in terms of the "iron triangles" of which they are a part. Iron triangles are "clusters of individuals [who] effectively make most of the routine decisions in a given substantive area of policy."[3] A typical iron triangle (in any policy area) includes members of relevant congressional committees having jurisdiction over the policy area, bureaucrats with jurisdiction paralleling that of the congressional committees, and private user groups having the greatest stake in the decision outcomes.[4] One of the most widely recognized types of iron triangle exists in the area of water policy.[5]

Members of water-policy triangles traditionally included bureaucrats from one of the federal agencies involved in building and maintaining water projects, members of development-oriented committees in Congress, and water-user groups at the local or state level. In this case, the historical sides of the triangle were the Reclamation Service (currently the Bureau of Reclamation), various committees in Congress having jurisdiction over water policy, and farmers served by Newlands Project waters and who were represented by irrigation

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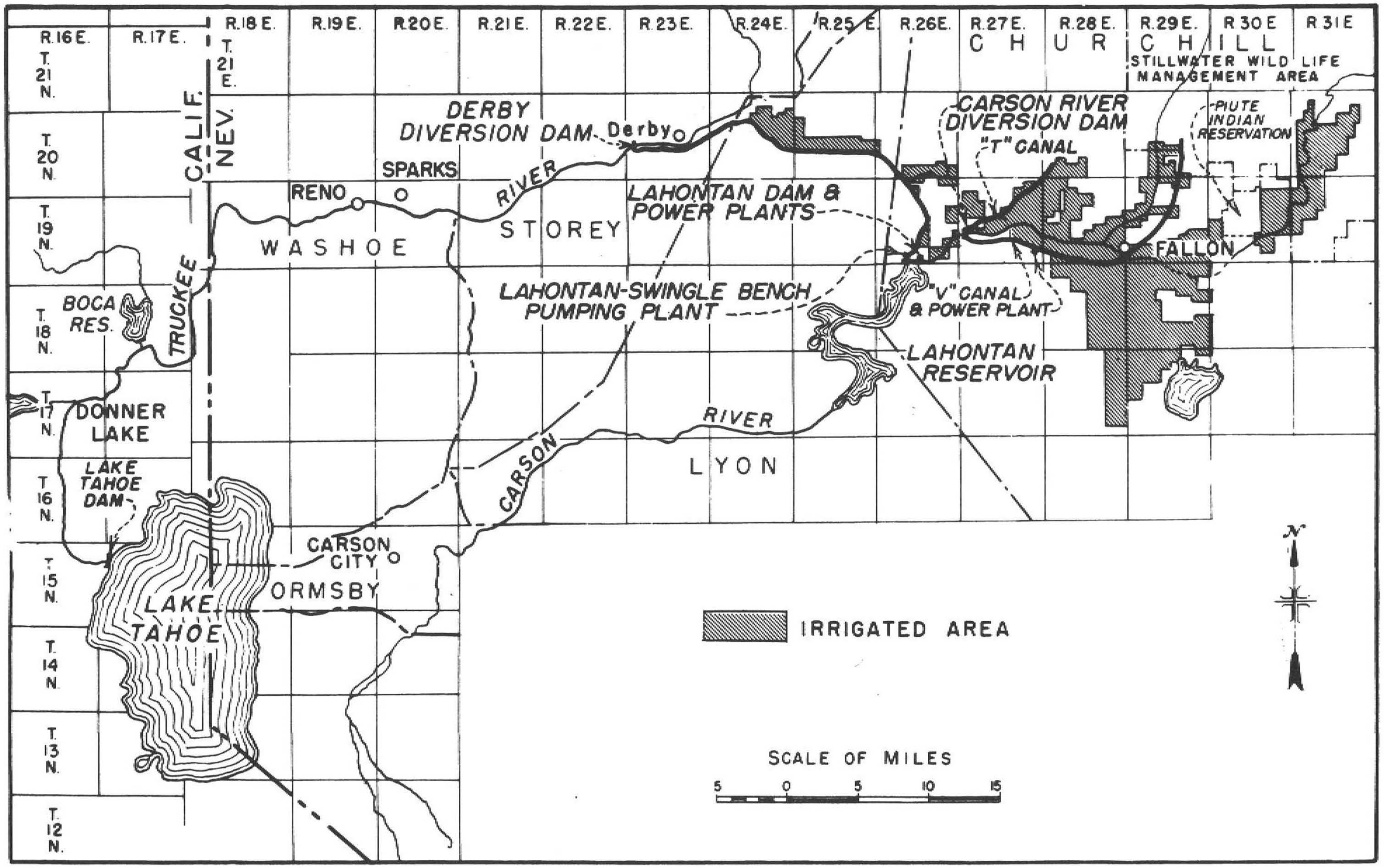
districts—here, the Truckee-Carson Irrigation District (TCID). Some observers viewed the 1990 act—and the negotiations that preceded it—as providing the mechanisms by which the iron triangle that had dominated the making of water policy in northern Nevada for decades could—or would—be broken.[6] Finally, given the complexity of the act that resulted, and the conflict that remained unresolved at the time of its passage, others noted that successful implementation of the act would prove daunting, at best.[7]

BACKGROUND

The history of conflict over water resources within and between the states of Nevada and California is long and complicated, especially the conflict that emerged among competing users within each state. For more than a hundred years, water interests in each state have tried to reconcile their conflicting water demands. Lake Tahoe, bordered by the central Sierra Nevada range, straddles the California-Nevada border. The Truckee River rises on the California side of the lake and flows northeast through Reno to terminate in Pyramid Lake. The Carson River rises elsewhere in the high Sierra south of Lake Tahoe. Some of its waters eventually reach the Stillwater Wildlife Management Area and the Carson Sink.[8] Given the bi-state nature of the watershed and the urban/rural stakeholders involved, it is not surprising that competition arose. The construction of the Newlands Project in western Nevada during 1903-1905 merely heightened the conflict by bringing additional interests and competing uses into play.[9]

The Newlands Project was one of the first major reclamation projects constructed by the Reclamation Service under the Reclamation Act of 1902. The purpose of the Newlands Project was to demonstrate that various public-works projects could make the desert bloom. The federal government built a vast surface-irrigation system to deliver Truckee and Carson river waters to farmers in and around the town of Fallon, Nevada.[10] During the early years, local interests largely dictated the allocation and use of water supplies, despite the efforts of the Reclamation Service to obtain more water from Lake Tahoe. Lake Tahoe property owners, power company officials, various irrigation districts, and individual farmers effectively defended their interests. Eventually disputes went to state and federal courts. A complex set of formal agreements, court decrees, and doctrines emerged to govern the allocation of the waters of Lake Tahoe and the Truckee and Carson rivers. The agreements did not settle the disputes completely or permanently, however.[11]

In 1955, the two states began negotiations on an interstate compact that would allocate the water that they held in common. That process took fourteen years. The disputed waters were allocated 90 percent to Nevada, and supplies were reserved to accommodate growth in the Lake Tahoe-Truckee area of California. California ratified the compact in 1970; Nevada did so in 1971. Congress



Map of the Newlands Project (*Nevada Historical Society*) refused to approve the compact, however, in spite of repeated attempts by the congressional delegations of both states to obtain it. Senator Paul Laxalt of Nevada attempted one last time to get the compact approved in 1985, to no avail.[12] Both states abided by the terms of that agreement, voluntarily, until passage and implementation of Public Law no. 101-618 in 1990.

Several factors contributed to the failure of the states to obtain ratification of the compact by Congress. First, the compact emphasized protection of the interests that negotiated it, to the exclusion of other interests that were by then demanding inclusion. Most notably, these included Native American, environmental, and urban interests. For example, the compact did not provide for the maintenance of the Pyramid Lake water levels or of the endangered fish species contained in the lake. This was in spite of the fact that diminishing lake levels (due to the diversion of water from the Truckee River to the Newlands Project had affected those fisheries. Under the provisions of the Endangered Species Act, the Lahontan cutthroat trout was a "threatened" species. The cui-ui fish, found *only* in Pyramid Lake, was "endangered" as well. Both were entitled to protection by federal law.[13]

Neither did the compact recognize reserved water rights of the Pyramid Lake Paiute Tribe under the Winters Doctrine of 1908. The reserved rights of Pyramid Lake were litigated under the Orr Ditch Decree of 1944,[14] which limited tribal rights to agricultural uses.[15] The Supreme Court later acknowledged that the government failed to meet its obligations as trustee for the tribe in that case, but refused to change the outcome. This is one of the major reasons that this settlement, and the many other legal strategies utilized by the tribe in this negotiation, rely on claims other than Winters.[16]

Negative environmental impacts to the lake also triggered litigation by both the Pyramid Lake Paiute Tribe and the United States government against the Newlands Project operators—the TCID—and most other users of Truckee River water in both states.[17] The tribe won some of those cases and was becoming increasingly successful in its efforts to increase flows into Pyramid Lake.[18]

Congress did not ratify the compact for other reasons as well. One of these had to do with the fact that the Newlands Project had negatively affected the Lahontan Valley Wetlands in general and the Stillwater Wildlife Management Area around Fallon in particular.[19] The national government felt that any compact sanctioned by it needed to contain provisions that would protect these valuable resources.[20]

A third significant factor had to do with the Fallon Paiute Shoshone Tribes. In 1890, 50 allotments, each of 160 acres, were assigned to the tribes, along with an additional 146 allotments of the same size in 1894 (more than 31,000 acres overall). These parcels were located in what later became the Newlands Project Area. Following authorization of the Newlands Project, the government entered into contracts with the tribes, in which 186 tribal members gave up their 160-acre parcels to the Newlands Project in exchange for 186 lots of 10 acres each, with water rights attached (to be served by the Newlands Project, provided in perpetuity and at no cost to the tribe). The project supplied water sufficient to serve 1,860 acres of Indian land, upon its completion. The tribe later increased its acreage, bringing the total amount of acreage that had water rights attached to 5,400 acres. The project never served these additional water rights, however, a fact that led to the compensation provisions of the 1990 act.[21]

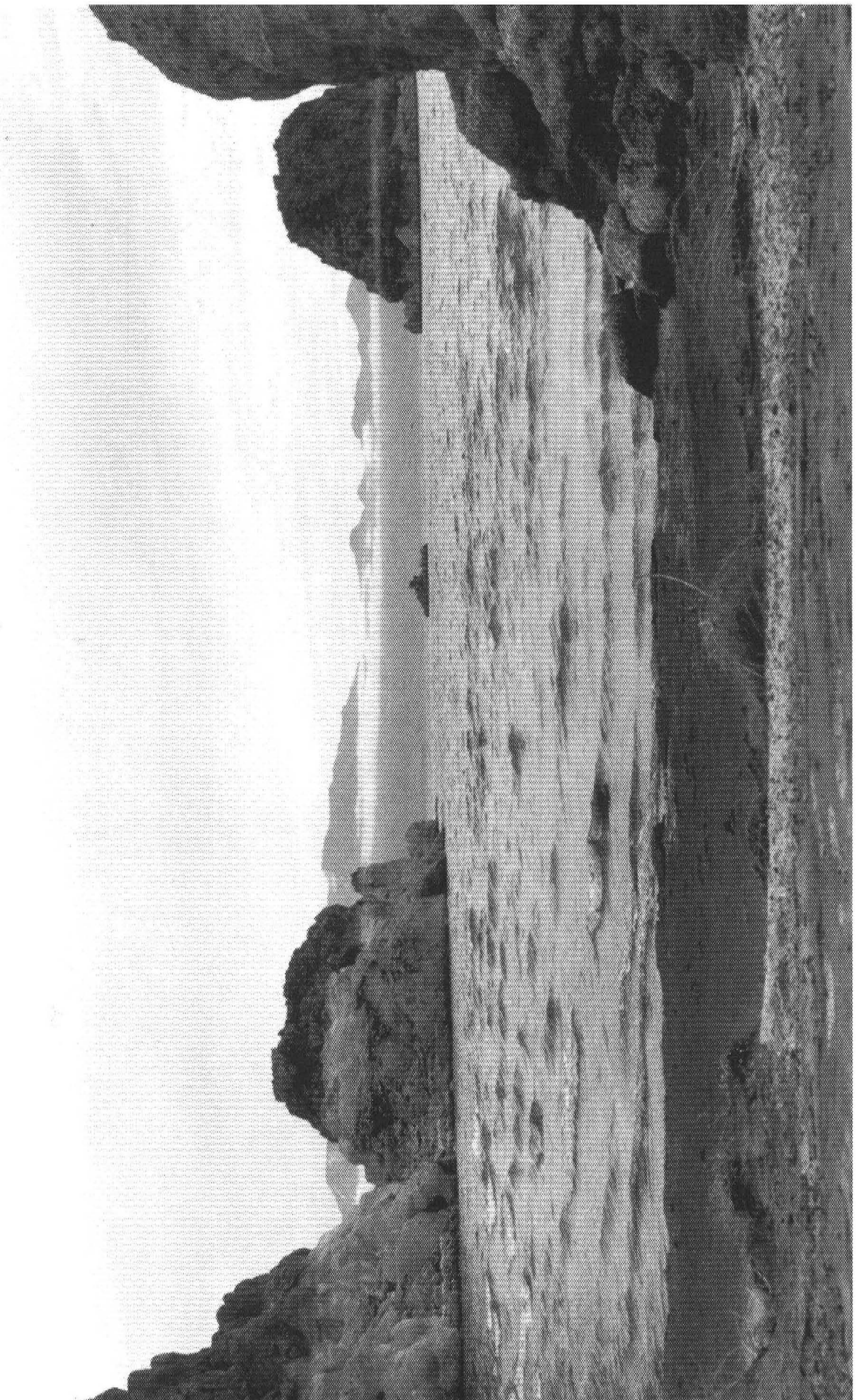
Under these circumstances, U. S. Senator Harry Reid began the round of negotiations that eventually led to passage of the Truckee-Carson-Pyramid Lake Water Rights Settlement Act in 1990.

Negotiating the Settlement

Senator Reid and his staff privately brought the major players together at facilities provided by the University of Nevada in Reno for the first round of negotiations in early 1988. These included Sierra Pacific Power Company (represented urban consumers and interested in obtaining authority to store additional water supplies for drought protection and future growth), the Pyramid Lake Paiute Tribe (interested in preservation of a traditional culture, economic development, and compensation), the state of Nevada (interested in protecting its historical water rights from encroachment by California), the state of California (interested in water for future growth), the TCID (interested in protecting its access to TCID-project waters for irrigated agriculture), and the national government (interested in promoting negotiated settlements of such conflicts).[22] By June of 1988, the TCID had withdrawn from the negotiations.[23] In spite of the obstacles encountered by the negotiating parties, they reached an agreement in less than two years. President George H. W. Bush signed Public Law no.101-618 on November 16, 1990.

The Negotiated Settlement

Public Law no. 101-618 contains two titles. Title I (The Fallon Paiute Shoshone Indian Tribes Water Rights Settlement Act) settled the seventy-year-old dispute between the Fallon Paiute Shoshone tribes and the national government. Section 102 of this title authorized appropriations for the Fallon Paiute Shoshone Tribal Settlement Fund of $43 million, disbursed over the fiscal years 1992 through 1997. Congress subsequently appropriated the funds, and the secretary of the interior placed this money in interest-bearing deposits with the Treasury Department. The act dictated that income from the fund be used only for the purposes of tribal development. Further, per capita distribution of the fund, among all individual members of both tribes, was limited to 20 percent of the fund's annual income. The tribes were required to develop an economic plan,



Pyramid Lake. (*Nevada Historical Society*) in consultation with the secretary of interior. The plan has been completed, approved, and adopted.

Section 103 of Title I limited the acquisition of land and water to no more than 2,415.3 acres and 8,453.55 acre-feet, respectively, per year to be added to the reservation and held in trust by the United States for the tribes. Added water rights plus existing water rights may not exceed a total of 10,587.5 acre-feet per year. Section 103 also authorized the secretary of the interior to pay the TCID's normal fees for delivery of water to the reservation.

The legislation required the tribes to dismiss all claims against the United States because of its failure to deliver water to the reservation, as well as to drop other claims that they made in two lawsuits against the national government.[24] They were also required to drop their objections to the Operating Criteria and Procedures of 1988,[25] agree to the limits on water rights noted above, and agree to be bound by the secretary's plan to close the TJ drain system (because of the heavy metals that had accumulated in it). By the end of 1992, the tribes had agreed to all of the above. To date, then, Title I of Public Law no.101-618 is fully implemented.

Title II of the Act (The Truckee-Carson-Pyramid Lake Water Rights Settlement Act) is much more complex. The purposes of Title II are to:

(a) Provide for the equitable apportionment of the waters of the Truckee River, Carson River, and Lake Tahoe between the State of California and the State of Nevada
(b) Authorize modifications to the purposes and operation of certain Federal Reclamation project facilities to provide benefits to fish and wildlife; municipal, industrial, and irrigation users; and recreation
(c) Authorize acquisition of water rights for fish and wildlife
(d) Encourage settlement of litigation and claims
(e) Fulfill the goals of the Endangered Species Act by promoting the enhancement and recovery of the Pyramid Lake fisheries
(f) Protect significant wetlands from further degradation, enhance the habitat of many species of wildlife which depend on those wetlands, and other purposes (Section 202)

Section 204 addresses the issue of interstate allocations. Section 204(a) deals with the Carson River, and essentially confirms the provisions of the Alpine Decree of 1980.[26] This decree tabulated all of the water rights on the Carson River, as well as the priority dates of those rights—and verified the existence of almost 24,000 acre-feet of Carson River water rights in California. The remainder was reserved for the state of Nevada.[27]

The act sets the maximum diversion from Lake Tahoe at 34,000 acre-feet per year from all sources, including groundwater. Of this total, "23,000 acre-feet per year [are] allocated to the State of California for use within the Lake Tahoe

Basin and 11,000 acre-feet per year . . . to the State of Nevada for use within the Lake Tahoe Basin."[28]

Allocations to California from the Truckee River basin are set at 32,000 acre-feet per year. Of this total amount, diversions of surface water are limited to 10,000 acre-feet per year. The legislation reserves all Truckee River water not specifically allocated to California to Nevada.[29]

Section 205 directs the secretary of the interior to negotiate an operating agreement with California and Nevada "after consultation with such other parties as may be designated by the Secretary [of Interior], the State of Nevada or the State of California."[30] The parties are still negotiating the terms of the Truckee River Operating Agreement. The draft agreement may be ready by the end of summer 2004. The law stipulates that the secretary of the interior, the states of California and Nevada, the Pyramid Lake Paiute Tribe, and Sierra Pacific Power Company must all sign the agreement before it can go into effect.[31]

Wetlands protection is the subject of Section 206. The intention of this section is to ensure that the Stillwater marshes remain a viable migratory waterfowl wetland of at least 25,000 acres, even in drought years. Section 206 authorizes the secretary of the interior to purchase up to 75,000 acre-feet of water rights from willing sellers in order to accomplish this goal. The state of Nevada agreed to furnish $9 million to help acquire the necessary water rights. A Nevada bond measure for this use passed in November 1990; a fund of $5 million became available and approximately $4.5 million expended.[32] To date, the secretary has acquired 17,500 acre-feet of water for Stillwater. This number represents 23 percent of the targeted goal.

The act also authorizes the secretary to use federal facilities (dams, waterways, ditches) to deliver water to the wetlands and to reimburse the TCID for the expenses involved. This was to be accomplished through a contract with the TCID for continued operation of the Newlands Project facilities built by the Bureau of Reclamation. The parties signed the contract on November 26, 1996, with an effective date of January 1, 1997.[33] The contract is in effect for twenty-five years, with provisions made for possible five-year extensions after the contract expires. To date, the Stillwater National Wildlife Refuge includes 77,520 acres.

As part of the plan to obtain more water for the wetlands, the act directs the secretary of the navy to study the possibility of water-saving measures at the Naval Air Station in Fallon, Nevada. It also directs the secretary to fund a demonstration project "with the goal of restoring previously irrigated farmland in the Newlands Project area to a stable and ecologically appropriate dryland condition."[34] The Navy is to transfer water rights it no longer needs to the United States Fish and Wildlife Service. To date, no such transfers have occurred, most probably because of expanded defense activity at Fallon Naval Air Station.

Another provision of Section 206 specifies that title to Carson Lake and

Pasture be conveyed to the state of Nevada for use as a state wildlife refuge. The conveyance is far from certain; the details of this transfer are still being negotiated. The secretary of the interior is also authorized to transfer the Indian Lakes area to the state of Nevada or Churchill County for use as a park. Since the national government would set park policy while the state assumed the costs of administering it, the state of Nevada is not interested in the transfer. As of this writing, no discussions have occurred between Churchill County and the national government on this point.

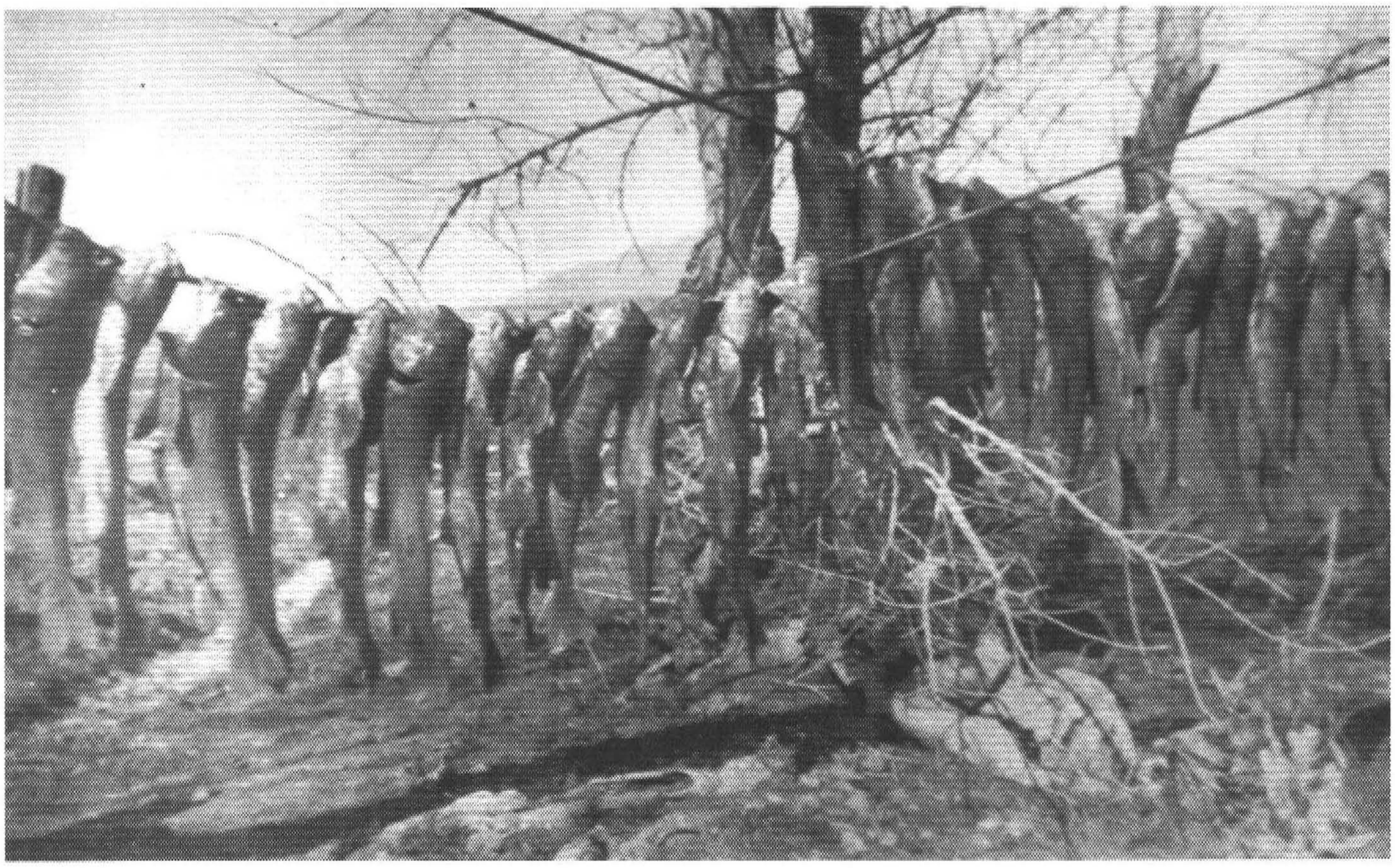
Section 207 deals with the Cui-ui and Lahontan Cutthroat Trout Recovery and Enhancement Program, and directs the secretary of the interior to update and implement plans for the recovery and conservation of both species. The second revision of the Cui-ui Recovery Plan was approved on May 15, 1992; the recovery plan for the cutthroat trout was approved on January 30, 1995.

The act directs the secretary of the army to include in its ongoing reconnaissance level study of the lower Truckee River "a study of the rehabilitation of the lower Truckee River to and including the river terminus delta at Pyramid Lake, for the benefit of the Pyramid Lake fishery."[35] Feasibility studies call for:

(a) Restoring riparian habitat and vegetation cover
(b) Stabilizing the course of the Truckee River to minimize erosion
(c) Improving spawning and migratory habitat for the cui-ui
(d) Improving spawning and migratory habitat for the Lahontan cutthroat trout
(e) Improving or replacing existing facilities, or creating new facilities, to enable the efficient passage of cui-ui and Lahontan cutthroat trout through or around the delta at the mouth of the Truckee River, and to upstream reaches above Derby Dam, to obtain access to upstream spawning habitat.[36]

The original reconnaissance study of 1988 examined modifications to the lower river below Vista. The study, completed in 1992, found that there are "significant resources in the lower Truckee River Basin that are threatened by past and present work and land related development practices."[37] An expanded report, released in July 1995, recommended additional improvement studies that began in 1997. A draft Feasibility Report appeared in February 1999. The report "estimated proposed improvements at Marble Bluff Dam at approximately $5 million."[38] A draft Environmental Restoration Report was completed. The parties are currently waiting for clarification of the Pyramid Lake Tribe's ability to cost-share construction before beginning the improvements..

This section of the act also authorizes the secretary of the interior to purchase water rights from willing sellers for the benefit of the Pyramid Lake fishery. In the late 1980s, the tribe sued the Environmental Protection Agency over the quality of the lower Truckee River water. Co-defendants in these suits in-



A string of cui-ui, a prehistoric fish found only in Pyramid Lake, Nevada. (*Nevada Historical Society*)

cluded the cities of Reno and Sparks, Washoe County, the Department of the Interior, the Department of Justice, and the Nevada Division of Environmental Protection. In an effort to settle the question out of court, the various parties involved in the suit began negotiations on how to improve water quality in the lower Truckee River. The negotiations ended with the development of a Truckee River Water Quality Settlement Agreement, signed by all parties on October 10, 1996.

Under this agreement, the cities of Reno and Sparks and Washoe County agreed to spend $12 million, with matching funds provided by the national government, for the purchase of water rights for the sole purpose of improving water quality in the river. The plan is to use the water to dilute the discharge from the wastewater facility below the Vista gauge in order to meet national water quality standards. The water will be stored in federally owned reservoirs upstream and released as required. In exchange, the Pyramid Lake Paiute Tribe agreed to drop the lawsuit. Thus far, the parties have purchased approximately 3,500 acre-feet of water rights for these purposes.[39]

Section 208 establishes a $25-million Pyramid Lake Fisheries and Development Fund. This section mandates the maintenance of the principal (in 1990 constant dollars), and specifies that the interest income is to be used for the operation and maintenance of fishery facilities, excluding Marble Bluff Dam and fishway. The release of any funds by the federal government is contingent upon the tribe releasing "all claims of any kind whatsoever against the United States for damages to the Pyramid Lake fishery resulting from the Secretary's acts or omissions prior to the date of enactment of this title."[40] In effect, this absolves the national government of the harm it did to Pyramid Lake when it constructed the Newlands Reclamation Project and diverted water from the Truckee River. The tribe must also assume responsibility for the operation and maintenance of the facilities.

The act also created a $40-million Pyramid Lake Paiute Economic Development Fund, disbursed over a five-year period that ended in 1997. Both principal and interest are and will continue to be available to the tribe for investment in accordance with the tribe's economic development plan. The tribe cannot use any of these funds for gaming or gambling development, however. The tribe cannot access these funds until the Truckee River Operating Agreement has entered into effect. The parties are negotiating the terms of that agreement.

In an effort to improve the Newlands Project, Section 209 authorizes the expansion of the uses to which project waters may be put to include fish and wildlife (including endangered and threatened species), municipal and industrial water supplies, recreation, water quality, and any other purposes recognized as beneficial under state law. The act prohibits the secretary from increasing Truckee River diversions to the Newlands Project to meet these expanded uses to levels above those allowed under the 1988 Operating Criteria and Procedures (OCAP). It also stipulates that diversions from the Truckee River must not conflict with any existing court decrees.[41]

As mandated by this section, the secretary also conducted a study of the feasibility of increasing the efficiency of the Newlands Project from 63 percent to 75 percent. The Department of the Interior released the report in April 1994; the report concludes that although the targeted efficiency is possible, it would require the acquisition of an additional approximate 20,000 acre-feet of water to replace the loss of return flows to the system.[42]

Section 209 also authorizes the secretary to study water banking, recreational use of project facilities, re-use of effluent, and cancellation of repayment obligations to the Bureau of Reclamation by the TCID. None of these may be undertaken until the TCID has "entered into a settlement agreement with the Secretary concerning claims for recoupment of water diverted in excess of the amounts permitted by applicable operating criteria and procedures."[43]

The recoupment issue centers around the claim by the Pyramid Lake Tribe that between 1973 and 1988 the irrigation district diverted more than 1,057,000 acre-feet of water from the Truckee River than it was entitled to divert. "The District, though, maintained that in court stipulations, the government had agreed not to enforce compliance with the OCAP until a final EIS was completed."[44] Hearings commenced in the United States District Court for the District of Nevada during March and April of 2002 before Judge Howard McKibben.[45] The court is still deliberating.

Section 209(j) addresses Operating Criteria and Procedures, and directs the secretary of the interior to enforce the provisions of the OCAP of April 15, 1988, at least until December 31, 1997, unless the "Secretary decides, in his sole discretion, that changes are necessary to comply with his obligations, including those under the Endangered Species Act, as amended."[46] Further, this provision prohibits any court or administrative tribunal from setting aside or changing the OCAP in any manner.

As previously mentioned, on November 26, 1996, the Department of the Interior and the TCID signed a twenty-five-year contract for the continued operation and maintenance of the project by the TCID. The secretary of the interior, Bruce Babbitt, decided to exercise his sole discretion to change the OCAP and published revised rules in the *Federal Register* on December 9, 1996. The new regulations went into effect December 16, 1997. It should be noted here that the 1988 OCAP had reduced maximum allowable diversions from the Truckee River by setting target storage in Lahontan at 215,000 acre-feet, which is about two-thirds of its total capacity.[47] The target storage date was from January to June. The 1997 criteria reduced the storage to 174,000 acre-feet for the same period, however. Under the 1988 rules, water could not be stored in Truckee reservoirs before April 1. Therefore, water stayed in the river and was diverted to the Truckee Canal before the amount of snowpack could be calculated. In some years, this resulted in needlessly diverting Truckee River water to Lahontan Reservoir. Under the 1997 rules, storage may begin in January, which gives water planners a tool with which to predict with reasonable accuracy the amount of water available for diversion to the Lahontan Reservoir in order to meet the requirements specified in the regulations.

This change will probably mean more water for Pyramid Lake and less for Lahontan Valley Wetlands, since water that was diverted and then became spilled or excess water went to Stillwater. As a consequence, the Fish and Wildlife Service may well be forced to purchase more water rights for the marshes than it would have had to under the old rules.

The final section of Public Law no. 101-618 deals with various miscellaneous issues. It requires the settlement of litigation in the cases of *Pyramid Lake Paiute Tribe v. California, United States v. Truckee-Carson Irrigation District, Pyramid Lake Paiute Tribe v. Lujan,* and *Pyramid Lake Paiute Tribe v. Department of the Navy,* as well as in motions in Federal Energy Regulatory Commission Docket no. 3-9530, filed by the Pyramid Lake Paiute Tribe. The act mandates settlement of these cases before any disbursements can be made from the tribe's economic development fund—or before the interstate allocations of water between California and Nevada go into effect. During a Truckee River Operating Agreement negotiation meeting held on March 12, 2001, the tribe's lawyer, Bob Pelcyger, noted that two of these cases had been dismissed without prejudice (those in which Lujan and the Navy were listed as defendants). He also noted that the Department of Justice continued to work on settling the other cases.

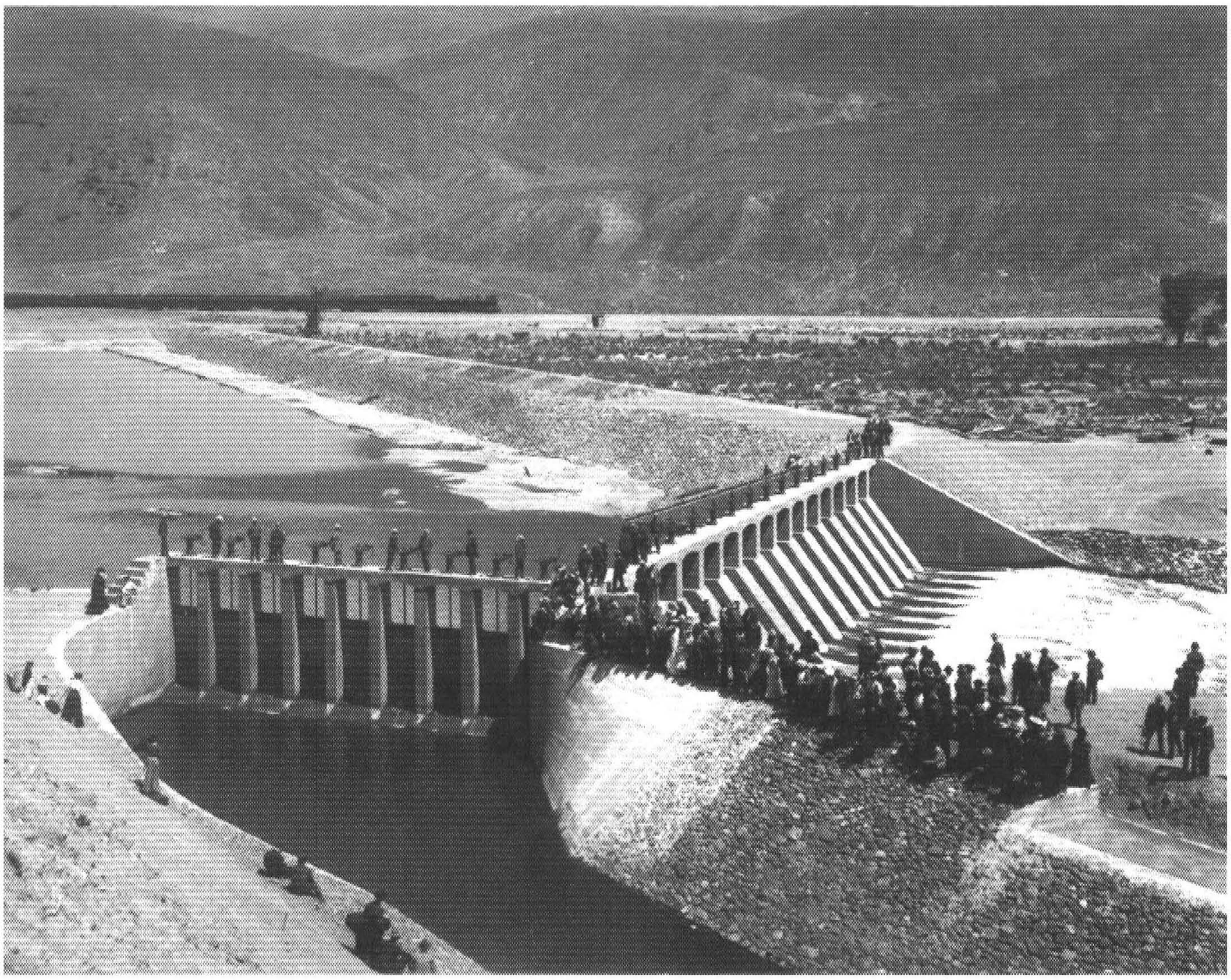
There is also a requirement that the Pyramid Lake Tribe's claim to Truckee River water that is not subject to vested or perfected rights must be satisfied before the interstate allocations can go into effect. This requirement was placed in the law in response to a number of water-rights applications for Truckee River water pending before the state engineer.[48]

This section also transfers Anaho Island to the Pyramid Lake Reservation and orders that it be held in trust by the United States for the tribe with administration by the United States Fish and Wildlife Service "as an integral component of the National Wildlife Refuge System for the benefit and protection of colonial nesting species and other migratory birds."[49] And finally, Section 210(a)(3) asserts the following,

> On and after the effective date of section 204 of this title, except as otherwise specifically provided herein, no person or entity who has entered into the Preliminary Settlement Agreement as modified by the Ratification Agreement or the Operating Agreement, or accepted any benefits or payments under this legislation, including any Indian Tribe and the States of California and Nevada, the United States and its officers and agencies may assert in any judicial or administrative proceedings a claim that is inconsistent with the allocations provided in section 204 of this title, or inconsistent or in conflict with the operational criteria for the Truckee River established pursuant to section 205 of this title. No person or entity who does not become a party to the Preliminary Settlement Agreement as modified by the Ratification Agreement or the Operating Agreement may assert in any judicial or administrative proceeding any claim for water or water rights for the Pyramid Lake Tribe, the Pyramid Lake Indian Reservation, or the Pyramid Lake Fishery. Any such claims are hereby barred and extinguished and no court of the United States may hear or consider any such claims by such persons or entities.

It is clearly the intent that once the Truckee River Operating Agreement is in effect, the various signatories cannot take each other to court. Further, the Pyramid Lake Paiute Tribe forfeits any additional claims to water by accepting the funds specified in this act. The TCID will not likely sign any of these agreements. What course of action the TCID will take in the future remains to be seen. One possible course could be to claim that the Truckee River agreement was violated. That is to say, that the United States government has unilaterally altered it without the concurrence of the TCID. Another possible course of action is for the TCID to challenge the constitutionality of Section 210(a)(3), which bars parties from further litigation on these issues.

It appears that although implementation of the various provisions of this act has been slow and, at times, fraught with difficulties, the process has been and is moving forward. One remaining major obstacle remains, however: the Truckee River Operating Agreement must be finalized and signed by all required parties. As of the time of this writing, in early 2004, the parties are still negotiating this part of the settlement.



The Congressional party and local dignitaries preparing to raise the gates of the Derby Diversion Dam after the christening of the newly completed headworks, June 17, 1905. (*Nevada Historical Society*)

Conclusions and Observations

There is little doubt that political solutions are easier and cheaper to obtain than continued litigation. The water scholar Daniel McCool has pointed out that this is one of the attractions of negotiation over litigation.[50] Moreover, it has not been so much a case of "implementing" the various provisions of Public Law no. 101-618 as it has been a case of continuing to negotiate solutions to issues both that were specified in the law and that arose in the process of implementation. Therefore, a culture of negotiation emerged to replace the culture of litigation that had existed for much of the twentieth century. While it is true that most of the key court decisions made over the decades are embodied in the settlement, no over-all settlement emerged that was acceptable to all or even most of the parties involved. It did not seem likely that such a solution would ever occur. The settlement act, however, does provide a comprehensive, acceptable solution for all parties except the TCID. The TCID has opted not to participate, and made itself largely irrelevant. It does not seem possible that this party alone will be able to upset the negotiated agreement.

Seen in this light, one need not lament the fact that this process has taken almost fourteen years, with the end still not in sight. There will be, in our view, no "end" to implementation of this act, as the parties continue to negotiate—and re-negotiate—solutions to problems as they arise and as the context changes. The basic structure of the settlement will remain unless changed by Congress. This structure was intended to facilitate cooperation and minimize conflict among the parties, a situation not likely to change unless the context changes dramatically.

It is also important to note that the political system—the arena in which politics, policy, and law come together—dealing with allocation and use of water in northern Nevada spans more than a hundred years. In the course of that time, much has changed (actors, agencies, law, natural resource values, intergovernmental environmental policy, as well as regional demographics and dynamics). The length of time during which these water-resource issues remained open and on the table brought new interests into play.

Tribal interests, in particular, learned how to empower themselves. A tribe attempting to defend its sovereign treaty rights in the early years did not even have a seat at the policy-making table. By the time that the parties began to negotiate the terms of Public Law no.101-618, the tribes were effective, serious players with powerful allies. They were able to take advantage of legal and political representation in a national environmental context that was sensitive to their grievances and the issues about which they cared.

Most assuredly, the national context permitted the Native American point of view to be taken more seriously in the last decades of the twentieth century than it had in previous decades. Key pieces of national legislation, such as the Clean Water Act, the National Environmental Policy Act, and the Endangered

Species Act, as well as administrative changes in the Department of the Interior, enlarged the scope of executive authority and federal funding to facilitate settlements such as this. Key stakeholders, with the help of Senator Reid, negotiated accommodations previously not possible by providing real dollars to the local water-rights market to drive the allocation of water rights to meet the terms of the settlement.

The complexity of this resource arena has also changed over time. Previously, controversies involved only agricultural interests, urban users, water-purveying public utilities, and urban-development interests clashing unsuccessfully in various courts. The disputes now involve national and local environmental interest groups, urban interests in the Truckee Meadows, the Department of Defense (Fallon Naval Air Station), emergent Native American traditionalism, and direct negotiations facilitated by congressional staff. Moreover, the conflict-resolving institution historically used, the judicial system, failed repeatedly to provide lasting solutions. Although the courts are still relevant, such conflicts have proved far more amenable to political settlements embodied in statutes than to resolution by the courts.

It also seems clear to us that the iron triangle that dominated the making of water policy in northern Nevada for most of the twentieth century has been broken. The existence of an iron triangle presumes three sets of participants who, together, control policy making in a given policy area. The TCID not only does not represent one leg of a powerful policy-making triangle, it is now a relatively minor player. While we may well hear from the TCID in the future, it is likely to be through the judicial system if it decides to litigate the terms and outcomes of this settlement.

It appears, then, that a network of organizations and individuals has emerged to control water policy making in this region—an "issue network" with multiple members, each seeking to have its interests and point of view reflected in policy outcomes.[51]

NOTES

1Leah J. Wilds, Danny A. Gonzales, and Glen S. Krutz, "Reclamation and the Politics of Change: The Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990," *Nevada Historical Society Quarterly*, 37 (Fall 1994), 173-77; Richard L. Acton, "Peace or Truce: The Truckee-Carson-Pyramid Lake Water Settlement Act," (Ph.D. diss. University of Nevada, Reno, 2002).

2Acton, "Peace or Truce: The Truckee-Carson-Pyramid Lake Water Settlement Act."

3Randall B. Ripley and Grace A. Franklin, *Congress, the Bureaucracy, and Public Policy* (Pacific Grove: Brooks/Cole Publishing Company, 1984), 10.

4*Ibid.*, 5-10.

5Daniel McCool, *Command of the Waters: Iron Triangles, Federal Water Development, and Indian Water* (Tucson: University of Arizona Press, 1994), 5.

6Wilds *et al.*, "Reclamation and Politics of Change."

7*Ibid.*

8The Walker River, a third river shared by the two states, also originates in California, and one branch terminates in Nevada at Walker Lake. The Walker River was not included in these negotiations and thus is not included in this article.

9W. Turrentine Jackson and Donald J. Pisani, *A Case Study in Interstate Water Resource*

Management: The California-Nevada Water Controversy 1865-1955 (Davis: California Water Resources Center, 1973).

[10]John M. Townley, *Turn This Water into Gold: The Story of the Newlands Project* 2nd. ed. (Reno: Nevada Historical Society, 1998), 13-41.

[11]*Ibid.*; W. Turrentine Jackson and Donald J. Pisani, *Lake Tahoe Water: A Chronicle of Conflict Affecting the Environment* (Davis: California Institute of Governmental Affairs, 1972). See also W. D. Rowley, "The Newlands Project: Crime or National Commitment?" *Nevada Public Affairs Review*, 1 (1992), 39-43.

[12]Rowley, "The Newlands Project: Crime or a National Commitment."

[13]Martha C. Knack and Omer C. Stewart, *As Long as the River Shall Run: An Ethnohistory of Pyramid Lake Indian Reservation* (Berkeley: University of California Press, 1984); Timothy G. Haller, "The Legislative Battle over the California-Nevada Interstate Compact: A Question of Might versus Native American Right," *Nevada Historical Society Quarterly*, 32 (Fall 1989), 198-221.

[14]Final Decree, *U.S. v. Orr Water Ditch Co.*, in Equity Docket no. A-3 (D. Nev. 1944).

[15]Under the Winters Doctrine [*Winters vs. U.S.*, 207 U.S. 564 (1908)] and subsequent case law, the tribe should have been entitled to enough water to serve all the purposes for which the reservation was made. According to Winters, those reserved rights should have been entitled to a priority date on which the reservation was created—in this case, 1859. In 1973, however, the United States government attempted to assert reserved water rights for Pyramid Lake (*United States v. Truckee-Carson Irrigation District et al.*, supra, 649 F.2d at 1289); in 1974, the tribe intervened in this case, asserting the same rights. The court held that the Orr Ditch Decree had settled the matter and dismissed both claims. On appeal, the Ninth Circuit Court of Appeals reversed that portion of the order dismissing the complaints as to the TCID and held that the United States breached its responsibilities to the tribe when it represented both the project and the tribe. The Supreme Court, upon further appeal, concluded nonetheless that the parties were bound by the terms of the Orr Ditch Decree, which could not be undone (459 U.S. 904, 1983).

[16]In 1989, the Chief Justice of the United States Supreme Court, William Rehnquist, expressed his dissatisfaction with the Winters Doctrine: "It's not a total exception as if it stood there on a plateau all by itself while all the appropriative rights went down to nothing. There is no doctrine of water law that elevates one water right over the other to that extent" [*Wyoming v. U. S., et al.* 889- 309 (25 April 1989) 3]. Native American tribes became, after this case in particular, extremely reluctant to base claims to water rights on the Winters Doctrine. For a more complete discussion of these cases, see Townley, *Turn This Water into Gold.* For a discussion of the impact of recent Winters Doctrine court cases on tribal water rights, see McCool, *Command of Waters.* See also Daniel McCool, *Native Waters: Contemporary Indian Water Settlements and the Second Treaty Era* (Tucson: University of Arizona Press, 2002).

[17]Elmer Rusco, "The Truckee-Carson-Pyramid Lake Water Rights Settlement Act and Pyramid Lake," *Nevada Public Affairs Review*, 1 (1992), 9-14; United States Senate, Select Committee on Indian Affairs, *Providing for the Settlement of Water Rights Claims of the Fallon Paiute Shoshone Indian Tribes*, Report No. 101-555 (Washington: U.S. Government Printing Office, 25 October 1991).

[18]Townley, *Turn This Water Into Gold.*

[19]The Stillwater Wildlife Management Area is the largest primary wetlands in Lahontan Valley. Over 410,000 ducks, 28,000 geese, and 14,000 swans use the area during their spring and fall migrations. Bald eagles winter there. In 1988, Lahontan Valley was designated as a Western Hemisphere Shorebird Reserve. The Truckee-Carson river system supplies water to these wetlands. See George Laycock, "What Water for Stillwater?" *Audubon Magazine* (November 1988), 14-24; United States Senate, *Providing for the Settlement.*

[20]During the twentieth century, the Stillwater wetlands in northern Nevada have been depleted by up to 85 percent. In addition, the previously clean water supplies in some of the remaining wetlands have been contaminated by agricultural runoff from irrigated fields.

[21]United States Senate, *Providing for the Settlement.*

[22]The background to this settlement that is provided in this article is based upon and drawn in part from previous research conducted by its authors, working together or with other scholars. For a more comprehensive discussion of both the background and the negotiations, see Wilds, *et al.*, "Reclamation and Politics of Change."

[23]Some observers indicated that the TCID believed it had no incentive to participate; it simply had nothing to gain—and everything to lose. It had become obvious to TCID that any additional

water for development, recreation, and environmental purposes outside the Newlands Project must come mainly from the project's water rights (Willis F. Hyde, Truckee-Carson Irrigation District Water Master, interview by Richard Acton, April 4, 1996). The Fallon Paiute Shoshone Tribe's legal position was so strong that Senator Reid believed it was not necessary to bring them into early negotiations. The remedy that would be forthcoming had already been agreed upon. See Wilds *et al.*, "Reclamation and Politics of Change."

[24]*Pyramid Lake Paiute Tribe v. California*, S-181-378-RAR-RCB, United States District Court, E. Dist. of California; *Pyramid Lake Paiute Tribe v. Lujan*, S-87-1281-LKK, United States District Court, E. Dist. of California; *Pyramid Lake Paiute Tribe v. Department of the Navy*, R-86-115-BRT, United States District Court, E. Dist. of Nevada.

[25]Both the Fallon tribes and the TCID objected to the 1988 OCAP. Eventually the TCID voted to accept the directives while the tribes went to court. The major points of contention were (1) while headgate entitlements remained constant at approximately 226,500 acre-feet, the maximum allowable diversion of 371,055 acre-feet in 1988 was reduced to 346,985 acre-feet in 1992 and subsequent years, (2) a mandated increase in efficiency from 61 percent in 1988 to 68.4 percent in 1992 and subsequent years, (3) enforced conservation measures, and (4) a requirement that the irrigation season be contracted by two weeks.

[26]Final Decree, *The United States of America vs. Alpine Land & Reservoir Company, et al.*, Civil no. D-183 BRT (October 28, 1980).

[27]It should be noted here that these provisions do not supersede allocations of the Carson River that had been apportioned by state law in both states prior to passage of Public Law no.101-618. Public Law no.101-618 does assert, however, that such additional allocations shall not exceed 1,300 acre-feet per year by depletion for use in the state of California and 2,131 acre-feet per year by depletion for use in the state of Nevada.

[28]Section 204(b).

[29]Section 204(c).

[30]Section 205(a)(1).

[31]Section 205(c).

[32]Richard Grimes, United States Fish and Wildlife Service, interview by Richard Acton, September 26, 2001.

[33]Contract no. 7-07-20-X0348 between the Bureau of Reclamation and Truckee-Carson Irrigation District, November 26, 1996.

[34]Section 206(c)(4).

[35]Section 207(b)(1).

[36]*Ibid.*

[37]Michael A. Campbell, Project Manager, Sacramento District, United States Army Corps of Engineers, e-mail to Richard Acton, November 16, 2001.

[38]*Ibid.*

[39]Donald Mahin, Engineer, Washoe County Water Management Planning Division, interview by Richard Acton, October 4, 2001.

[40]Section 208(a)(2)(E)(i).

[41]Section 209(b).

[42]United States Department of the Interior, Bureau of Reclamation, *Final Report of the Secretary of the Interior to the Congress of the United States of Newlands Project Efficiency Study* (Washington, D.C.: U.S. Department of the Interior, Bureau of Reclamation, (1994), 155.

[43]Section 209(h)(1).

[44] John M. Townley, *Turn This Water into Gold.*

[45]Mary Connelly, Senior resident aide to Senator Harry Reid, interview by Richard Acton, September 26, 2001.

[46]Section 209(j)(2).

[47]Townley, *Turn This Water into Gold*, 82.

[48]Section 210(a)(2)(B).

[49]Section 210(b)(2).

[50] McCool, *Command of Waters.*

[51]Hugh Heclo, "Issue Networks and the Executive Establishment," *The New American Political System*, Anthony King, ed. (Washington, D.C.: The American Enterprise Institute, 1978), 87-124.

Book Reviews

Trusteeship in Change: Toward Tribal Autonomy in Resource Management. Edited by Richmond L. Clow and Imre Sutton (Boulder: University Press of Colorado, 2001)

This is a big book, both in length and in scope. It tackles several large topics—the evolving nature of federal trusteeship, the legal status of American Indians, and the varieties of natural-resource management—from a number of disciplinary angles: geography, forestry, history, economics, political science, archaeology, community planning, and the law. Richmond Clow and Imre Sutton assembled a diverse group of scholars, giving them free range to explore the nature of trusteeship and resource management at the point where tribal sovereignty, federal agencies, and environmental interest groups intersect. Their goal was "to disseminate knowledge, offer critical judgments, but not to propose policy" (p. xix) in what the editors envisioned as a kind of "state of the state" commentary on the co-evolution of policy, cultures, and conservation. As with all books of collected essays, *Trusteeship in Change* is at times just big and long. At other times it is powerfully insightful. This is a book to be mined rather than read for its narrative coherence, but, oh, what can be mined!

Part One contains four essays illustrating the historical role of the federal trustee in managing Indian resources. Clow describes the erosion of Northern Ute treaty hunting rights; Terry Anderson offers a free-market economist's take on land tenure and agricultural productivity that is naïve in its acceptance of agricultural statistics and in its inattentiveness to native cultural motives and economic decision making; Katherine Weist explores the power of other federal agencies and non-Indian water users in circumventing Bureau of Indian Affairs (BIA) trusteeship and Indian water rights; and Alan McQuillan dismisses the notion of any uniquely "Indian" forestry management models in the twentieth century, demonstrating the imposition of such models on tribes by the trustee rather than proving the inherent absence of localized indigenous use patterns.

Part Two examines the rising tribalism of the Indian New Deal era. Peter Booth describes how the Tohono O'odham subverted BIA conservation programs in order to maintain their own cultural livestock economy; Clow demonstrates how the Rosebud Lakota reconsolidated fragmented heirship lands into a viable tribal land enterprise; Sutton addresses the problems of access to and control of "sacred" sites on non-trust lands; and, in one of the most literate essays, Diane Krahe offers a nuanced assessment of the competing interests and pragmatic political and economic decisions made by the Confederated Salish and Kootenai Tribes in creating the Mission Mountains Tribal Wilderness area.

Part Three deals with indigenous and multiagency management of Indian resources since the self-determination era of the 1970s. Sutton begins by stressing the importance of recognizing confusing and overlapping jurisdictional issues among tribes, states, and the federal government on trust, fee, and alienated Indian lands; Laura Kirwan and Dan McCool assess the positive nature of negotiated water settlements where Indians and environmentalists are often at odds; and Lawrence Lesko and Renée Thakali describe the incorporation of Hopi traditional ecological knowledge in the management of the Kaibab National Forest. Unfortunately, Theodore Jojola's concluding commentary on the preceding essays is as inadequate as his dichotomous typology of what distinguishes Indian from non-Indian planning and organizational styles.

Trusteeship in Change is at its best uncovering the complex realities hidden in simple terms such as Indian Country, sovereignty, trusteeship, and conservation. It highlights the problems of negotiating Indian land use and protection across differently held—private, tribal, trust, federal, state, non-Indian—and differently managed lands. At points it illustrates the problematic nature of Indian decision making, economic development, and attendant environmental impacts. Unfortunately, the editors consciously chose to omit consideration of hazardous-waste disposal, a very timely topic illustrating the tensions between economic development and ecological images, between self-determination and trust protection, between the environmental racism of business and government and the rational decisions of semi-sovereign and self-interested peoples. Despite recognition of the problematic image and reality of the "ecological Indian," there is still a lot of muddy thinking going on between the lines in this book. While some of that reflects the weight of past historiography, we still get scholars citing fictitious words attributed to Chief Seattle as evidence for an indigenous land ethic that did exist on various levels, but never as systematically or simplistically as we historicize it.

As topical collections of essays go, *Trusteeship in Change* is well above average, and at times it sparkles. The editors do an excellent job introducing each of the three sections of the book with essays that provide the larger political context rather than simply summarize the chapters to come. Some chapters are carefully crafted commentaries, while others are illustrative case studies. Each reflects the structure and language of the particular author's discipline, contributing to a diversity of perspectives but also a dissonance of tone. Each is provocative enough to spark disagreement and discussion. Those looking to mine the book for sources will be disappointed. Essay endnotes seem oddly dated, and the very brief and selective bibliographical note—undoubtedly a result of publishing imperatives rather than editorial shortcomings—does little to convey the richness and extent of the historiography. In some ways this book is better suited for specialists, but general readers will find much to surprise them and complicate what they thought was a simple story of Indian land tenure and resource use. And that is good.

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Sierra Crossing, First Roads to California. By Thomas Frederick Howard (University of California Press, Berkeley, 1998)

Sierra Crossing does an admirable job of describing both the history and geography of the Sierra Nevada's first roads. It also provides a comprehensive examination of private, local, state, and federal road building in the Sierra and a review of the Central Pacific Railroad as well. Thomas Howard successfully covers this broad range of transportation activities in a concise and interesting fashion. Especially valuable is his examination of the Pony Express, the Wagon Road Act (1857), and railroad surveys.

The time frame covering the road building is short, from the 1840s to the 1860s. During this brief period, the crossing of the Sierra Nevada went from a death-defying feat reserved only for the bravest to an entertaining and scenic coach ride suitable for east-coast urbanites. The rapid development of various trans-Sierra transportation systems is at the heart of this book.

The book is organized in a logical fashion beginning with a physiography of the Sierra and a review of nonwheeled transportation in the Sierra. The author then proceeds with a detailed description of road and railroad construction across the Sierra Nevada. Howard provides an excellent differentiation of the motives of local, state, and federal road builders and also sheds some light on the major players in the road-construction industry in California.

Using both primary and secondary sources, the author has done a terrific job of describing the location and rationale for the earliest trans-Sierra wagon roads. Not surprisingly, various routes were promoted vigorously by towns that would receive the economic benefits that came with the arrival of hundreds of immigrants. The author also discusses specific cutoffs and how word-of-mouth speculation about them often resulted in lost time or, in some cases, a deadly delay.

This book is as much about history as it is about geography, and Howard knows his history. He asserts correctly that although the 1841 Bidwell-Bartleson Party was the vanguard of a forthcoming wave of migration, their failure to establish a trans-Sierra route that others could follow has left this party in the historical dust. It is also good to see that Howard reminds the reader that the Donner Pass is misnamed and rightly should be called Stevens Pass for the party that traveled through there in 1844 —two years prior to the doomed Donner Party. Explaining the problems associated with finding Peter Lassen's route on the Applegate Trail, the author is on target when he writes, "Lassen's mental map was defective" (p. 72). Peter Lassen was a notoriously poor pathfinder, and woe to any party that ended up under his command. John Bidwell, a longtime associate and friend, joked that Peter Lassen "could get lost going around a tree."

The book also has a nice selection of before-and-after photos. The pictures indicate that some locations, such as Sugar Loaf Mountain and Strawberry Station/Lodge on present-day Route 50, and the town Placerville, have maintained their importance as Sierra Nevada way stations for more than a century and a half. Just as interesting and informative is the transformation of the forests appearing in the backgrounds. In almost every pair of before-and-after pictures, the forests look healthier and more mature today than they did more than a hundred years ago. While the book has a handful of maps showing overland routes, passes, and major waterways, this reviewer would have liked to have seen more maps in the book. Perhaps it would have been better to provide maps for each chapter or to gather them centrally, providing easy access for quick referral. But this is a minor quibble that in no way detracts from the over-all value of this excellent book.

In sum, this is one of the most important books published on the California Trail in years. Howard has been successful in synthesizing vast amounts of primary and secondary material and has transformed it into a readable and precise examination of a people and a place. By focusing on the trans-Sierra routes, Howard explores the most difficult and most sensationalized aspect of the overland trail. The liberal and judicious use of diary entries and other first-hand observations help bring this important study to life. For the amateur and professional historian alike, this is an important book and a valuable contribution to California and western history.

Michael J. Gillis
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Robert Laxalt: La voz de los vascos en la literatura norteamericana. By David Río Raigadas. Foreword by William A. Douglass (Madrid: Servicio Editorial de la Universidad del País Vasco—Euskal Herriko Unibertsitateko Argitalpen Zerbitzua, 2002)

Author David Río Raigadas has published a book on the late Basque-American author Robert Laxalt, entitled *Robert Laxalt: la voz de los vascos en la literatura norteamericana* (*Robert Laxalt: The Voice of the Basques in North American Litera-*

ture). The work focuses on Robert Laxalt's life and career as a journalist and novelist, and includes a critical analysis of his work. David Río is a professor of American literature at the University of the Basque Country (Vitoria-Gasteiz), Department of English Philology. He has been a visiting scholar at the Center for Basque Studies at the University of Nevada, Reno, on several occasions. During his visits to Reno he met several times with Robert Laxalt, and subsequently published several articles about him. Río's book is a comprehensive study of Laxalt that deals with all his published works and clarifies many of the symbols and themes that lie beneath Laxalt's unsophisticated narrative style.

In the foreword to the book, William A. Douglass, one of the most authoritative voices on Basque subjects throughout the world, says that Robert Laxalt's work is the voice of a whole community, a mythic concept of the Basques that has been kept and maintained in the memory of many young people who had to cross the Atlantic to become sheepherders in the American West. Professor Río sets out to describe and analyze what made this work possible and how it became a milestone for generations to come.

The first section of the book describes Laxalt's life as a son of immigrants in Carson City and a student at the University of Nevada in Reno, and includes his experience as a reporter and his role as director of the University of Nevada Press (1961-83). The main section deals with Laxalt's works, including a book-by-book analysis of his work, and ends with an evaluation of his stature as a writer and advocate for the Basques. Laxalt told Río that he preferred having his books speak for themselves instead of giving elaborate explanations about them. While he follows Laxalt's advice, extracting most of his information from the books, Río also uses personal interviews with Laxalt to compose a fresh and convincing portrait of Laxalt the writer alongside Laxalt the person.

In his study, Río shows us how Laxalt put an end to the literary and social invisibility of the Basque diaspora in the United States, as part of the over-all trend in contemporary American literature that displays a multicultural approach and a wider ethnic diversity. In this regard, Laxalt's first book, *Sweet Promised Land* (1957), brought a new vision to the literary world, capturing for the first time the voice of the Basque-American community. In addition to its literary success, Laxalt's first book served as a platform for the writer to help launch the Basque Studies Program at the University of Nevada, Reno—now known as the Center for Basque Studies.

Using many examples from Laxalt's novels, Río discusses the most important literary archetype in Laxalt's work, the Basque sheepherder of the American West. Today, all scholars on Basque immigration refer to that archetype when they try to understand the immigration experience of the Basques in the New World. Río shows that Laxalt not only reflects the experience of his parents' generation, but he also deals with his own generation of Basque-Americans, and anticipates some of the issues that will be critical for a Basque-American identity in the new millennium.

Río emphasizes an important aspect of Laxalt's work: his ability to combine the views of the Basques who emigrate to the Americas with the views of Basque Americans who go back to their parents' country searching for their roots. In this sense, Laxalt's position is unique, being the son of an immigrant and at the same time an American author who has traveled to the Basque Country. From his journeys there, Laxalt gathered a well of information that allowed him to give us a portrait of traditional Basque society from a modern American perspective. In any case, Río is always careful to emphasize that Laxalt does not claim that his own vision of the Basques is the only real one, but is only the one that is closest to his heart. Thus, Río shows how Laxalt shares many of the traits that he sees in Basque people, although he is always willing to criticize them when he thinks that they are not right, for example, regarding certain social prejudices.

According to Río, Laxalt has a special gift for incorporating in his books autobiographical features that take a literary form. In this age where nonfiction books and memoirs abound, Laxalt stands as an able cultivator of a genre that requires a delicate balance between fact and opinion. Río describes how Laxalt achieves this balance between his personal views and experiences and his literary reflections. Thus, Laxalt's style, concise and accurate, without elaborate rhetoric, offers the reader a "fluid, direct, and minimalist prose, without artifice." At the same time, Laxalt manages to give his tales a lyrical sensibility that goes along with its narrative rhythm, and a subtle sense of humor.

Among Laxalt's books are *In a Hundred Graves: A Basque Portrait* (1972); the trilogy *The Basque Hotel* (1989); *Children of the Holy Ghost* (1992); and *The Governor's Mansion* (1994); and *A Time We Knew: Images of Yesterday in the Basque Homeland* (1990). All of them are carefully analyzed by Río, who also keeps a critical eye on his subject—he is not shy of pointing out certain shortcomings in Laxalt's last books. All in all, Río's study is an excellent source for those interested in knowing more about this author's work and his relationship with the Basque Country, and serves as a companion for Laxalt's writing memoirs, *Travels with My Royal.* It is amazing that a writer like Laxalt, who describes in such a vivid way the Basque immigrant experience in the United States and has been twice nominated for the Pulitzer Prize in fiction, has not been extensively translated into Spanish and Basque. Río's study could help correct this situation, for it is an informed book that accurately describes Laxalt's achievements and his place in North American literature. Now, we can only wait for Río's book to make the trip to this side of the Atlantic and to be translated into English.

Javi Cillero Goiriastuena

Making the World Safe for Tourism. By Patricia Goldstone (New Haven: Yale University Press, 2001)

If Patricia Goldstone is correct, tourism—the "biggest business in the world" —is threatening to get bigger. And this, she implies in her recent book *Making the World Safe for Tourism,* will not be a good thing. As developing countries continue to open up to tourism in the name of economic improvement and "democracy," Goldstone argues that they do so at the risk of desecrating their countrysides with hotels and other developments catering to the tourist trade and, simultaneously, displacing indigenous populations and destroying the very cultural traditions they are trying to promote. She points out that developing countries remain dependent on funding from international lending institutions in order to develop their tourist infrastructures, and that those profiting most from that tourism have deposited their earnings into foreign banks while locals struggle to adjust to the new tourist-driven economy. There is no clear-cut evidence, Goldstone argues, that tourism is the democratizing panacea that its promoters claim, and, should the tourist industry falter, countries that have turned their economies wholly in that direction become highly vulnerable.

A well-traveled freelance journalist, Goldstone is well equipped to make such assertions. In this book, she witnesses first-hand the attempts of certain countries to focus their efforts on tourism and interviews a number of individuals who either are close to the tourism-development process—or are affected by it. These include everyone from high-ranking tourism officials to the acquaintances she makes in the hotels of Havana, the suqs of Istanbul, and the streets of West Beirut—courageous travel for someone who twice describes herself as "a nice Jewish girl from Beverly Hills" (pp. 125, 180). Goldstone's descriptions of the people she meets along the way also make for lively writing and captivating reading, and at times the book is worthy of a travel narrative from the likes of Paul Theroux or V.S. Naipaul.

But only at times is this so. Goldstone's attempt to wrap her personal encounters within a totalizing frame that explains twentieth-century tourism as intimately tied to the rise of multinational corporations (such as American Express, Standard Oil, and Boeing) and international lending institutions (such as the International Monetary Fund and the World Bank) compel her to spend the bulk of the first four chapters providing anecdotes concerning the ascent of these various organizations—based upon a sparse number of secondary sources and with a glaring lack of footnotes. These chapters offer some useful background, but they are referenced only infrequently once she hits the ground in Cuba, Ireland, and the Middle East, encountering internal political conditions and people who appear largely unconcerned or unaffected by large-scale governmental efforts to develop tourism. Rather than a cohesive, integrated text, Goldstone has essentially provided two books: one a series of stories about particular institutions and individuals who have, in one fashion or another, attempted to make the world "safe for democracy" (and tourism); and the other a travelogue of Goldstone's encounters in various countries that are turning to tourism to boost their economies. The presumption is that the institutions Goldstone discusses in the first half of the book have made possible the circumstances she encounters in the second half, but connections between the two are not so obvious.

There are other problems with what is, on the whole, an uneven book. With a concentration on foreign policy and ways that local governments have attempted to remake their economies for their citizens, it is not always apparent that tourism is the principal focus of this book. Her chapter on Ireland, for example, spends more time detailing the growth of the movie industry than it does on how that industry has affected tourism. Even the book jacket, which features Goldstone's photograph of a new billboard advertising "cheap chic" in a bombed-out section of central Beirut (the same image appears on page 186), suggests more about the homogenizing forces of globalization than it does about tourism per se. The idea of tourism as a global phenomenon might be Goldstone's point, but her often detailed analyses of particular local issues suggest the distinctiveness of those places, undermining her implication that the whole world is being made "safe" for tourism.

The photographs that accompany the text create further ambiguity. Some make political points with appropriate captions that mirror or supplement information in the text; many others, however, are of picturesque landscapes or architectural ruins with laudatory or matter-of-fact captions more appropriate for a guidebook. The photographs are also too small, low in contrast, and crowded together in chapters five and seven to make those chapters resemble a hastily compiled travel album. To some extent, those chapters *do* constitute a travel album, and yet it is never entirely clear from the images (or the text) whether Goldstone wishes to celebrate scenic vistas and sites of historical import or decry the increasing dependence of developing countries on tourist dollars. Indeed, her travel experiences often read as a promotion for the very process she is trying to denigrate.

At the book's conclusion, Goldstone returns to her original conviction that an economic reliance upon tourism is a disaster waiting to happen. In an epilogue of sorts, entitled "The End," she begins with a hypothetical riot in New York's Times Square on New Year's Eve, 2010, fueled by an angry mob fed up with an economy reeling from a slowdown in the tourism sector. Her chilling last page points to the vulnerability of such economies when she recalls a United States State Department warning published in a December 1999 issue of the *New York Times:* It instructs Americans to avoid large holiday crowds, based upon credible threats "possibly related to planned attacks by Islamic fundamentalist Osama bin Laden" (p. 259). Goldstone argues that such government-issued warnings amount to a form of "social control" that can restrict tourism, just as they can promote it—a "more insidious" action than a definable act of terrorism. In the wake of the attacks of September 11, 2001—four months after the book's publication—one wonders not only whether Goldstone still considers such warnings "insidious," but whether the world is truly "safe" for tourism anymore.

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Mormons and Mormonism: An Introduction to an American World Religion. Edited by Eric A. Eliason (Urbana and Chicago: University of Illinois Press, 2001)

In anticipation of "welcoming the world" to its headquarters at Salt Lake City for the 2002 Winter Olympics, leaders of the Church of Jesus Christ of Latter-day Saints announced that they would no longer accept the term *Mormon* as a shortcut to identifying the organization. Founded in upstate New York in 1830 as the Church of Christ, the sect quickly went through lengthening name changes leading to its current unwieldy moniker. Nevertheless, church founder Joseph Smith expressed his fondness for the nickname Mormon (taken from the Book of Mormon), which he said was an ancient term meaning "more good." Furthermore, for more than a century and a half, friends and foes alike have almost universally used *Mormonism* to label the theology and the movement, and *Mormons* to identify believers. As a result, the idea that this practice will change by church dictum, except among the Mormons themselves, seems to most observers naïve and its fruition most unlikely.

At about the same time the church was attempting to rid itself of the label, Eric Eliason, an English professor at Brigham Young University, was assembling his anthology of previously published essays on Mormonism, "an American world religion." Ironically, among the church's prime motives for attempting to jettison the word Mormon is the need to convince people that the sect is indeed Christian, as its real name distinctly states. As all of the selections in Eliason's book clearly reveal, however, the question is not so easily answered, given the remarkable theology of Mormonism, which takes it so far from the mainstream that most Christian clerics steadfastly refuse to grant Mormons status as true Christians.

The most gripping essay in the entire collection might be Methodist historian Jan Shipps's meandering but illuminating discussion of the question "Is Mormonism Christian?" in excerpts taken from her reminiscences of *Forty Years among the Mormons* (2000). Even Shipps, a very friendly non-Mormon scholar, ultimately waffles on the question. Although willing to allow Mormons to be their own type of Christians, she hedges her bets by saying that while it may be "distressing" to Latter-day Saints to be excluded from Christianity, this exclusion is less "parsimonious" than the Mormon practice of classing all non-Mormons as "gentiles." She then leaves the final answer to God's judgment (pp. 96-97).

Other exceptionally informative essays in the collection are Dean May's comprehensive description "Mormons," originally penned for the *Harvard Encyclopedia of American Ethnic Groups* (1980), Grant Underwood's "Mormonism, Millenarianism, and Modernity" from his 1993 book on the same subject, and Terry Givens's 1997 examination of anti-Mormon literature extracted from his *Viper on the Hearth.* Singling out these few as particularly interesting should not suggest anything negative about the remaining articles. Each adds to the satisfying feeling a reading of this book provides, a sense of having absorbed a balanced and surprisingly comprehensive analysis of Mormonism. Its only serious flaw is endemic to such collections: One tires of redundancy as each author plows some of the same ground. For example, most attempt some brief history of Mormonism.

The editor's well-documented introductory essay lays rather successfully a foundation for the structure that follows, and is itself another highlight of the volume. Indeed, it might have been well for Eliason to have skipped the collected-essays route to quick publication in favor of his own book-length analysis of his claim that Mormonism must now be recognized as a legitimate world religion instead of a bizarre cult, truly important only in the Mormon heartland of the intermountain West. Part of his evidence for his claim, however, is in the intrinsic nature of the anthology itself: "The fact that most of the essays in this collection were written by non-Mormons and published by presses outside of Utah underscores the increasingly broad influence of Mormon studies" (p. 6).

If this handy little book has faults other than the redundancy problem, they are rare and insignificant. The editor could not have done much better in the selection of both scholars and writings. That said, one could argue that these and other students of Mormonism might be making a proverbial mountain out of a molehill. It remains to be seen whether "Mormonism will become the first new *world* religion to appear since the Prophet Mohammed [*sic*] rode out of the desert," as Rodney Stark suggests in the concluding essay (p. 207). With only a few million active believers among the world's teeming billions, Mormon-ism has yet a very long way to go before it may lay claim to such an accomplishment.

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