Technological Backwardness in the Western American Mining Industry in the Nineteenth Century

By Roger Burt

The mining industries are, and always have been, the most international of industries. Across the globe they share common technology, personnel, organisation and sources of finance. However, their history is almost always written on a local, regional, or at best, national basis. This is an attempt to take an international perspective on one aspect of the industry as it developed at the end of the nineteenth century—a hazardous enterprise in comparative mining history. And it is deliberately provocative. Some might find the very concept of combining the words "backwardness" and "western" a fundamental challenge to the efficacy of the American way.

That provocation is intended to have a productive purpose however: to focus attention on the fundamental springs and processes of technological change, to place them in broad context, and, basically, to ask whether we always achieve what we might, or just what we must. What follows is a condensed version of an argument developed at greater length in an article published in the journal *Technology and Culture*, and the two should be read in conjunction by those interested in exploring the issues in more detail.[1] Thus far, that particular piece of coat-trailing has produced no response; will it prove more controversial here, in the home of mining history?

The Issue

The general presentation of American technological and economic history sketches a picture of a small, largely agrarian economy that was a major beneficiary of inward technology transfer to the mid-nineteenth century, but then began a process of rapid industrialisation which converted it to a world leader by the closing decades of the nineteenth century. More specifically, American industry is said to have superseded the British in the development of standardised, interchangeable parts, mass-production technology, and to have established a new system of manufacture which claimed global success in the twentieth century.

This process has been well documented in the context of the textile and machine-tool industries,[2] and has long been assumed—though is less well demonstrated in direct comparative terms—to have occurred in the mining industries.[3] Does the evidence actually support this latter conclusion? In particular, did western mines pioneer a new era of "mass-production mining" that was significantly different from the "selective mining" techniques inherited from Europe via South America? Or did they simply improve on old methods and follow in the wake of other world mining fields in the development of fundamentally new technologies?

Fundamental to finding answers to these questions is a division of emerging new technologies into the broad categories of minor and major innovation—the former simply improving an existing technique or making better use of existing knowledge, and the latter representing "strategic" departures into entirely new ways of doing things. The latter commonly involved exploiting new science, moving productivity and output onto a significantly higher plateau, and opening up new vistas for future minor modification and improvement.[4] Thus new developments in wagons might be seen as providing minor improvements to existing methods of road transport, while the introduction of the steam train was a strategic leap forward, transforming the speed, cost, and comfort of transportation, and unlocking an entirely new potential for the industry.

Similarly, in the mining industry we can trace a wide range of innovational improvements that squeezed greater efficiency and more output from existing mechanical principles, as well as a number of profound changes of technique that introduced entirely new methods of ore extraction and beneficiation which revolutionised labour productivity and unlocked reserves that might never have been workable using old methods. Our quest here is to evaluate the particular contribution of western mining to those two lines of development. Certainly there were many minor improvements, but what was its contribution to the strategic innovations that revolutionised world output of mineral resources? How do the principal innovations in western mining practice measure up?

The Evidence

In the placer-working sector of the industry, there were very few, if any, major improvements to the methods and machinery of production during the early gold rush years.[5] The technology used for early gold working in the West was almost entirely of medieval European origin, imported indirectly via South America, where the Spanish had adapted it for drier conditions. It was adopted previously by a small number miners who had worked limited gold deposits in the eastern states of North Carolina, Georgia, Virginia, and Alabama in the 1820s and 1830s, but most of the original Argonauts would have picked up the simple techniques of making and using the pan, cradle, and sluice "on the spot" from indigenous prospectors and Mexicans.

In this case, newly arrived, skilled European miners would have had little to offer—their domestic industry having long-since abandoned such techniques. Probably only the Chinese would have recognised techniques still commonly used in their own homeland. Nonetheless, it is important not to underrate the hand skills and simple operational improvements made during the period. Later, in gold districts around the world, workmen with experience in California would show the way with the best methods and techniques for the initial, low-cost exploitation of rich, high-grade deposits—but none of this amounted to a major improvement of an inherited technology.

This is not to say, however, that placering saw no technological improvement during the second half of the nineteenth century. Indeed, it experienced two strategic innovations that involved entirely new technical concepts and transformed the structure of the industry, greatly increasing output and labour productivity: hydraulic production and dredging. But of these, more below.

The situation in the initial ore-extracting stage of hard rock mining was not very different from that of placering down to the late 1860s. The basic techniques of hand-drilling shot holes and blasting with black powder were little changed since their original conception in Germany in the seventeenth century. Only the introduction of the Bickford safety fuse from the 1830s, itself a European invention, had produced any significant increase in miners' productivity.

Identifiable "American" innovations only began to emerge with large-scale underground mining in the northern Michigan copper districts and the rich Nevada silver mines from the 1860s. Most were minor improvements or adaptive changes in operating systems, however, and only a few attracted significant attention. Philipp Deidesheimer's square-set timbering system, originally developed for use in Comstock mines, but later employed in many western mining districts, was one such example; but even here clear European origins were demonstrable.

It was not until the beginning of the last quarter of the century that the requirements of large-scale, low-grade ore mining initiated a new era of *macro* innovation in this section of the industry. Some of these innovations were partly pioneered by American engineers, but nowhere did western mines seize a clear leadership. As late as 1906, Ihlseng and Wilson, reviewing tunneling techniques, referred only to various European systems, concluding that "we cannot claim any system of tunneling as our own, for neither the number of tunnels nor the difficulties encountered are as great as in the old world."[6] But again, more below.

Indigenous American engineers made important contributions in milling, but again they were incremental rather than strategic ones. From the mid-nineteenth century, through to the 1880s, western mining engineers produced a rush of well-adapted traditional machinery. "Californian stamps"—of anonymous local origin—greatly improved the speed and efficiency of ore reduction by introducing a simple operational modification to a machine otherwise little changed from its late medieval European design.

Eli Whitney Blake's "stonebreaker," invented in 1858, was more original and had a world-wide impact on preliminary ore preparation, mechanising what had previously been a highly labour-intensive manual process. The stimulation for its invention and its early use, however, came not from the mining sector, but from civil engineering, where it was designed to facilitate the preparation of foundation stone for road construction. It became part of the standard equipment for ore concentration only by later adoption.[7]

After crushing and grinding, the separation processes were much improved by new machinery developed by the Irish-born Michigan veteran William Bell Frue, and the American engineer Arthur Redman Wilfley. Both men gave practical expression to earlier European ideas of mobilising the base of the traditional buddle or table to make it self-clearing and to improve separation. The "Frue vanner," developed in Ontario in the early 1870s, improved on a moving belt principle first developed in Scotland by William Bruton in the 1840s, and had widespread national and international success because of its ability to recover fine slimes from low-grade ores and tailings.

The Frue vanner was superseded from the 1890s by the "Wilfley table," which used an improved shaking motion and the addition of surface riffles to the table to aid separation. Modified versions of this device remain in use today. Even with this new machinery, however, many mines continued to rely on more traditional European devices. Round buddles of unimproved English design were in common use at the Keweenaw and Comstock mines, for example, and mechanised Hartz jiggers were retained for treating tailings at the Homestake until the early years of the twentieth century.[8]

Much American originality is often claimed for the "pan amalgamation process" for recovering gold. Invented by Almarin B. Paul on the Comstock in 1860, this system came into widespread use in mining operations across the West, and greatly improved ore recovery. But again, it employed no new scientific principles. It simply and perceptively combined the long-established "cazo" and "patio" processes of mercury amalgamation into a new mechanised and more efficient process. Later modifications of the process to improve its capacity to deal with mixed ores were similarly mechanically ingenious but scientifically derivative—salt was introduced for preliminary chlorination on a principle that had been well tried and tested in the old Freiberg process, recently explained and developed by the German inventor Karl Frederich Plattner.[9]

This tinkering with established principles and old techniques, which characterised America's indigenous contribution to received machinery and methods, was of little consequence when compared with the truly strategic innovations that revolutionised mining and concentration techniques from the end of the nineteenth century. The former improved the productivity of traditional, labour-intensive selective methods in the working of relatively rich and shallow mines, while the latter moved the industry into an entirely new era of mechanised mass production of concentrates from deep, difficult, low-grade and complex ores.

This transformation was produced by just seven principal innovations, of which only one was entirely American, and one other was partly pioneered by American engineers. The conception and development of the other five were undertaken outside of the United States, and American mines came to use them only late and after considerable delay. By sector, two of these innovations were in placering, three in the extraction and handling of ores from hard rock mines, and two in separation and concentration. These may usefully be considered in turn, starting with the placering innovations.

The only strategic extractive innovation to be developed solely by American engineers before the beginning of the second or third decade of the twentieth century was *hydraulic* placering. Credit for this invention usually goes to the American-born placer miner, Edward E. Matteson, working in Nevada County, California, in 1853. Although it was to revolutionise placer working—substituting an entirely new era of large-scale and heavily capitalised "mass production" for the earlier simple, labour-intensive washing systems—hydraulicking appears to have evolved in a series of simple steps from the ancient European system of "hushing," or "ground sluicing," as it was known in the West.

The beginnings of this evolution may have started considerably earlier, possibly in North Carolina in the 1840s, and may even have been carried to the Pacific Coast by migrant miners, but the perfected system was clearly of Californian design. Continued technical improvements in the system encouraged its diffusion, and by the end of the 1850s it was in common use throughout the state. This success, however, proved its undoing, as downstream debris discharge caused flooding and conflict with farmers. By 1885, hydraulicking had been effectively brought to an end in all but the northwestern corner of California. It lived on and prospered in most other western gold mining districts—in Oregon, Colorado, Idaho, Montana, South Dakota, and latterly, the Yukon—well into the next century, but saw no further major improvement to technique.

Hydraulicking was exactly the kind of innovation that might have been expected in mining. It was capital- and resource-intensive mechanised production, specifically designed to economise on the use of relatively scarce and expensive labour. Nevertheless, as will be seen, it was rarely to be repeated, and it is significant that it stood outside of the underground mining sector proper and in an activity which had no important parallel in contemporary European experience.[10]

After the prohibition of hydraulicking, placer mining in California went into a major decline and remained largely moribund until the late 1890s, when a second strategic technology created the conditions for a major revival. This was the introduction of the *dredge*. Floated in a moving lake of its own creation, it was the brain-child of an Englishman, Charles Bell, and had been developed in New Zealand fifteen years earlier. As Clark Spence explains: "When the first successful American gold dredge was launched on Grasshopper Creek in Montana in 1895, three years before one proved its prowess in California and four years before one was introduced into Alaska, there were already more than half a hundred operating on a seventy-mile stretch of the Clutha River in New Zealand."[11] Given the ideal conditions for dredging in many parts of California, and the rapid progress made with design improvements once it had been introduced, the long delay in these first trials requires an explanation which it has not yet received.

In the hard rock sector, the principal strategic innovations did not take the form of particular machines or pieces of equipment, but came together in a generic application of *mechanical power*. It might be objected that water, steam, electrical, and internal combustion machinery were all developed outside of the mining sector and that none saw entirely new conceptual development within the industry during this period. Nevertheless, the adaptation and introduction of these power sources for a widening range of underground and surface mining operations underpinned the mechanisation and transformation of the metal mining industries during the second half of the nineteenth century. Their simple introduction can be ranked as a strategic change for the industry.

Again, American mines appear to have been slow in the adoption of old and new power sources, and to have been relatively inactive in making significant modifications for their wider use. Even in 1880, fewer steam engines were in use at all U.S. copper mines combined than those active in Cornwall alone fifty years earlier.[12] It probably was not until the 1890s that the numerous U.S. copper producers—the main users of steam power in the western mining districts—surpassed the then small and contracting Cornish industry in the general use of steam power. Not only were the number and size of steam engines limited, but the mechanical devices to which they were attached commonly showed a lack of technical sophistication and resistance to change and modernisation.

The slow pace of investment in mechanical power as a substitute for human labour was not restricted to steam alone. Notwithstanding the proximity of many placer and mining operations to running water, there seems also to have been a marked reluctance to exploit water power. In 1870, for example, only 134 water wheels were reported for all types of mining in the whole United States.[13] Similarly, the development of compressed air, as a means of transmitting power and mechanising work in the underground workplace, appears to have been pioneered in England from the early 1860s and taken up only later in America.

Even in the early twentieth century, there seems to have been a reluctance to embrace the advantages and economies offered by the internal combustion engine and electrical power. By that period electrical power was in widespread use in coal and metal mines in Europe, and South Africa's gold mines alone had installed nearly three hundred generators to power over six hundred motors.[14] In Mexico, electrical power for lighting and pumping made rapid progress from the 1880s, and by 1910 almost all of the important mines were fully electrified.

In the United States, however, electrical power amounted to just over 1 percent of the total horsepower generated at all western copper mines in 1902. Ihlseng and Wilson had been lecturing on electricity's advantages at the Colorado School of Mines since the 1890s, but concluded in 1906 that 'though the utility and economy of electricity for underground work have long been recognised by the mining engineer, the conservatism forced upon him by restrictive legislation has made its installation underground one of slow growth'.[15]

This type of conservatism appears to have extended all the way down to the substitution of animal for human muscle. In the Keweenaw mines, for example, where the pursuit of lower grades of copper required moving ever-greater tonnages, labourers pushing small tram cars remained the main method of haulage down to the 1890s. A couple of mines experimented with horses and mules, and one tried an underground locomotive in the 1880s, but it was not until the second decade of the twentieth century that wider success began to be achieved using electrically driven engines.

By contrast, horses were commonly employed in underground tramming in Britain from the mid-nineteenth century, and the Neu-Stassfurt mine in Germany demonstrated the economy of electric underground locomotives as early as the1880s. Even the small Greenside copper mine in northwest England successfully introduced electric haulage by the early 1890s.[16]

Similarly, aerial tramways—so particularly suitable for the topographical conditions of many western mining districts—relied for their conception and basic engineering development on work conducted by Europeans such as Andrew Hallidie, Charles Hodgson, Theodore Otto, and Adolph Bleichert.[17] Their designs found their fullest development in America and were later considerably improved by domestic engineers, but as in so many other areas, this western mining technology only followed where Europeans led.

While the introduction of flexible sources of mechanical power created the essential preconditions for fully mechanised ore production, it was the development of the mechanical drill and new chemical explosives that really gave practical expression to that process. Together they produced the largest jump in labour productivity ever in the industry, and released it from potential labour-supply constraints on its future growth and expansion.

Neither of these strategic technologies had a specific inventor. Both were the product of a long series of inventions and discoveries, each relatively minor in itself, that were the culmination of a truly international effort. That thread of development did not start in the mining industries, but with civil engineering and the problems of constructing cheap and rapid transportation. As with Blake's stone crusher, the fevered activity in this sector around mid-century seems to have been more capable of concentrating inventive minds on common problems than did the mining industry.

That appears to have been as true in Europe as in America. Thus it was railway construction engineers driving the Hoosac tunnel in western Massachusetts and the Mont Cenis tunnel under the Italian Alps in the 1860s, who first experimented with mechanical drills to speed up the tedious process of drilling shot holes. It could be argued that straight tunnel driving provided an easier opportunity for the first use of the large and cumbersome early drilling machines, but whatever the reason, these projects take the credit for including the first competitive trials of what was already emerging as a new area of mechanical engineering.

In America, a direct-acting device developed by Charles Burleigh proved the most successful design, while in Italy, a machine built by the Frenchman Germain Someiller had the greatest success. Although they needed considerable development and refinement, these two machines established technical principles that were to be incorporated in all future designs: that they should operate on a rotating percussion principle; that they should be direct, double-acting, driven by reciprocating pistons; and that the best form of motive power was compressed air, which was most conveniently compressed at surface and distributed underground.[18] While these machines may have been adequate for driving wide, straight railway tunnels, they were too large, heavy, and complex for use in the confined and difficult conditions of most underground mines.

Having shown the way, civil engineering gave way to the particular requirements of mining in the future development of this machinery. Inventors in Italy, Germany, France, Sweden, America, Australia, and Britain all strove to produce new designs that would be smaller, lighter, and more manoeuvrable, have greater simplicity in their components, and be more powerful and reliable.

Notwithstanding a plethora of patents, real progress was slow and painful. Mines that gave the early machines careful trials during the late 1860s and early 1870s found that they failed to live up to expectations, and continued to rely primarily on old hand methods. In 1880, the United States census concluded that, "in spite of the numerous improvements made in power drills, their use in the West is still limited."[19] Around the same time, a British observer reported that "drilling by machinery is still in its infancy."[20]

It was gradually becoming clear, however, that although good miners could drive holes in rock just as fast or even faster than machinery, they could not match its continuity and regularity, and that the need for mechanisation was pressing. Finally, a new generation of lighter and more versatile drills evolved through a series of minor improvement and modifications, and their true potential for ore extraction, not just development work, began to be realised.

By the early 1880s the era of true "mass-production mining" was at hand. In Michigan, for example, the Rand drill, manufactured in New York, was widely adopted by 1883, while in southwest England the development of the "Cornish Rock Drill," and various improved devices introduced from Germany, had a similar impact.[21] By the mid-1880s, a visitor to gold mines in Australia reported that rock drills were "widely distributed throughout the principal mining claims in Victoria, and no well-established mining company is without one or more of these effective machines."[22] By the late 1880s the Anaconda mine in Montana reported 138 machines in use.[23] Even in South Africa, where the friable structure of the rock in the higher strata on the Rand and the low cost of labour at first militated against mechanisation, rock drills were trialed in the late 1880s and rapidly adopted after 1892.[24]

In America, however, progress remained patchy and relatively slow. The large-scale producers of Michigan and Montana, for example, made good progress and remained in the forefront of technological change, but many smaller producers fell far behind. In the Tri-State lead and zinc district of Missouri, Kansas, and Oklahoma, a region dominated by small producers, the first machine drills were not introduced until 1890, and adoption thereafter was slow and small in scale. Everywhere, even in the most heavily mechanised mines, hand drilling continued alongside machine drilling into the early twentieth century.[25]

One important cause of the delay in the introduction of mechanical drills was their symbiotic relationship with the new generation of high explosives. These were needed to exploit the deeper holes the drills could drive, and thus the greater rock volume that could be broken, during the miners' shifts. Nitroglycerine-based explosives, developed in Europe from mid-century, provided this potential, but they produced debilitating fumes and were widely disliked by miners. They preferred to stay with established powders, which they knew and understood, and which reinforced their predilection for traditional hand-drilling.[26]

As in all areas of technological development, the introduction of a revolutionary device at one stage of an integrated production process might be threatened by a bottleneck further down the line. In this sense, the exploitation of new ore-breaking technologies could have been constrained by a failure to improve concentrating techniques—not only to handle higher tonnages, but also to achieve good concentrates from lower-quality ores. The improvements to traditional mechanical methods offered by Frue, Wilfley, and others, made some contribution to that task, but were clearly not adequate in themselves.

Meeting this challenge required a complete break with old selective techniques and the development of new "mass-production" systems. Fortuitously, two such new technologies emerged during the last two decades of the nineteenth century. The "cyanide" process revolutionised gold production and rescued it from the doldrums into which many sections of the industry had sunk from the late 1870s, and "flotation" facilitated the separation of complex non-precious metals.

The cyanide process emerged from continuing dissatisfaction with amalgamation techniques for the recovery of anything but clean gold, and from experiments with alternative leaching methods. In the mid-1880s, the Scottish scientists John Stuart MacArthur and the brothers Robert and William Forest developed a method for commercially exploiting the long-understood principles of dissolving and recovering gold with cyanide.

Patented in 1887, the technique was relatively easy, cheap, and efficient. By 1891 it was being rapidly taken up in the Transvaal, and two years later it was introduced into New Zealand, with a major impact on gold production in both countries. On the Rand, cyanidation transformed the working of low-grade ores; by the mid-1890s it was responsible for over a quarter of the district's rapidly growing output. The diffusion of the process was less rapid in Australia, but similar percentages were being derived by it in Queensland by the end of the decade.[27]

In America, however, the uptake was slowest of all, notwithstanding poor gold recovery rates with established amalgamation processes and successful trials of cyanidation in Utah and California in 1891. Robert Spude has shown, for example, how attempts by MacArthur to introduce the technique into the Colorado gold mines in 1889 failed for lack of investment, and that thereafter it took a five- or six-year struggle to convince the western mining fraternity of its utility.

Even then, adoption was slow. In 1897 there were still only forty cyanide works in the country, mainly confined to working complex telluride ores the Cripple Creek District of Colorado and assisting with operations in a few small districts in Utah, Nevada, Montana, California, and Arizona. In that year less than two hundred thousand ounces of gold were derived by the process, or less than 7 percent of total U.S. output. It became far more common after the turn of the century, with large mines such as the Homestake in South Dakota and the Empire in California investing in large systems, but in 1918 the cyanide process still accounted for no more than a third of U.S. production.

The Americans repeated their tardiness of innovation in the cyanide process south of the border, in Mexico. British engineers and mining companies—such as H. W. Trewartha-James and the Anglo-Mexican Mining Company—played a pioneering role in the introduction of the new technology there, while a large part of the American-dominated industry showed a tenacious prejudice against its adoption for all but simple ores. Only when the utility of the process had been firmly established did it make rapid progress, and by 1938 nearly two-thirds of the world's gold output was produced with this method.[28]

The reasons for the slow uptake of the cyanide process in the U.S. are unclear and probably result from a combination of several factors. Patent restrictions clearly played a role, but Spude has also drawn attention to the conservative reaction to "new processes" that developed in many western mining districts. This was itself partly a reaction to earlier failed pseudo-scientific scams and the damage inflicted on the reputation of the process by its association with the colourful Leadville bonanza king, Horace Tabor. Whatever the reasons, western mines proved exceptionally slow, not only in the development, but also the adoption, of one of the defining strategic technologies in the transition from selective to mass-production mining.[29]

What the cyanide process did for gold production, flotation did for the separation of complex non-precious ores, such as lead-zinc-copper mixes. In a recent review of the development of the process, Jeremy Mouat has described it as "one of the most significant advances ever made in ore treatment," and of "central importance to the smooth functioning of the international economy"—but one in which Americans played no significant part. Like cyanidation, its invention and evolution into an effective technology were the result of a truly international effort, but one mainly pioneered in Britain and Australasia.

The process worked on the principle of mixing crushed ore with oil and water and agitating the mixture to produce bubbles. Separation was achieved because of a complex process in which minerals attached themselves differentially to the rising bubbles, some of the particles from the pulp adhering to air and others to water. The first practical equipment to exploit these principles was developed in Britain by Frank and Stanley Elmore in the late 1890s, a patent being issued for the process in 1898.

Although the Elmores installed their equipment at various mines in north Wales and northern England over the next few years, the process was to have its greatest and most immediate effect in the lead-zinc mines at Broken Hill in Australia.

Here the process saw important modifications and improvements as a result of work by a number of engineers, such as the Australian Charles V. Potter, and the Englishman Arthur Cattermole. Its impact at Broken Hill was immediate and massive, and the research effort devoted to perfecting the process made Broken Hill, in Geoffrey Blainey's words, "the Athens of metallurgy" in its day.

Floatation was quickly tried in a number of the world's other mining districts, such as in South Africa and British Columbia, but the United States remained an island of relative conservatism. T. A. Rickard tells us of some early experiments in Utah, Nevada, and Idaho, but suggests that it was not until 1911 that the country saw its first successful plant, set up by James M. Hyde for the Butte and Superior mines in Montana.

Even then, the technology diffused slowly. It was not until the middle of the second decade of the century that copper producers began to appreciate it as a means to greatly increase ore recovery levels without increasing overall processing costs. Many major lead-zinc districts, such as the Coeur D'Alene area of Idaho, did not began to be affected significantly by the technique until the 1920s. As with the introduction of the cyanide process, patent law, and the litigation that surrounded it, may have played a part in this, but is unlikely to have been a primary cause of the slow adoption of the process.[30]

Explanations

If this proposition of the comparative technological retardation of western American mining is in any sense acceptable, explanations need to be considered for the relative strength of forces promoting and retarding technological change in the world's leading mining districts, as well as what local factors may have encouraged and facilitated new technologies. In this context, the assumption must be that innovative forces were stronger outside of the United States than within it. What were these forces?

Relative Resource Endowment and Technological Traditions

For most of the second half of the nineteenth century, the United States was the world leader in most sectors of the non-ferrous mining industry. It was U.S. gold, silver, copper, and lead that flooded world markets, and its mines that competitors needed to beat to stay in business. This performance was achieved not because America had lower labour costs or superior technology, but because its mineral deposits were richer and more easily worked than most others available at that time.

America's competitors in the older, thus deeper, and less heavily mineralised mining districts of Europe found their backs pressed to the wall to survive. Even though European fuel and labour costs were a fraction of those paid in most American mining districts—in Cornwall around a fifth of the expense in most western mining districts[31]—European mines labored under an absolute imperative to innovate, by mechanising production and maximising ore recovery rates, in order to survive. These were the principal areas of strategic innovation.

Having acquired the habit at home, Europeans practiced it in their ventures abroad, particularly in the development of new large, difficult, low-grade deposits, which could only be exploited by the lowest cost methods. Alan Jeeves has argued that "if an ore body similar to South Africa's had been discovered in Australia, Canada, or the United States it would almost certainly have been left in the ground, because of the inability to mobilise the right kind of work force."[32] It also needed the right kind of technology.

Entrepreneurial Attitudes

The development, and particularly the adoption, of new technology, both at home and in Britain's expanding overseas possessions, was greatly facilitated by entrepreneurial and management consultants, like John Taylor and Sons and Bewick, Moreing, and Co., based in the City of London. These experts had often cut their teeth dealing with increasing competition and declining ore prices in domestic mines, and they employed the best methods and machines and the most highly trained and experienced personnel in their widening excursions into mining in all parts of the world.

These men were drawn from mining schools in England and elsewhere in Europe, which frequently worked in close association with neighbouring departments of science, as well as with the best available overseas, including in America itself. Thus in 1904, the successful London-based international mining consortium Bewick, Moreing and Co., employed seventy-five technical-school trained personnel, of whom forty-six were Australian and twenty-two American. One of those talented American nationals, a senior partner in the company and the embodiment of the American dream of rages-to-riches success, was the future president Herbert Hoover. But he made his fortune abroad, not among his native western mines.

Although many European mining ventures, both at home and abroad, continued to rely on traditional "apprentice" or practically trained managers, many others were quick to see the advantages, in terms of flexibility and innovative zeal, of more formally educated executives. Thus the British Rio Tinto Company, formed in 1873 to work large pyrite deposits in Spain, rapidly substituted trained mining engineers for "practical" Cornish mining captains after the early 1880s, and paid premium salaries to recruit the best scientifically educated chemists, often hired in Germany.

In Britain, professionalism and professional development were also promoted by the formation of the Institution of Mining and Metallurgy in 1892. By 1905, with the near complete collapse of domestic non-ferrous metal mining, around two-thirds of its 1,374 members worked overseas, mainly in British-owned ventures in Africa and Australia. In doing so, they projected internationally not only the lessons learnt at home, but also the skills to confront and overcome new challenges.[33]

The Profile of Technological Development

During the last decades of the nineteenth century, mining technology stood at a crossroads between the final development and elaboration of an old "mechanical" tradition, initiated in the middle ages or earlier, and a new "scientific" system, based on the practical exploitation of recently discovered chemical and electrical knowledge. While many American mines could afford to be conservative and almost complacent in their continued use of simple "old" machines and methods to work rich new deposits, European mines were driven to find new and improved ways to reduce costs and make small savings in lost ore and metal. Further, while America's free enterprise miners took a short-term view of their prospects and rushed for quick profits, many European mines, such as those in Germany, were state-owned and engaged in carefully planning the most efficient long-term exploitation of their ore reserves.

When American mines, such as those on the Keweenaw, began to work deeper, lower-grade, and more complex ores, a "wake" of new-generation, European-inspired technologies already existed for them to exploit. At most they would only need to join in advanced contemporary research and development—as with the perfection of rock drills—rather than to undertake the full burden of pioneering efforts.

Also, while mining education in America stressed the "practical" and spread itself thinly across a broad range of scientific and managerial subjects, European mining schools were moving toward a greater emphasis on theoretical and scientific study. Their graduates were commonly regarded as more advanced in "new" subjects, such as analytical chemistry, assaying, and complex underground engineering. Even in Britain, where the "practical" tradition also continued to dominate mining school curricula to the end of the nineteenth century, informal scientific education, facilitated by easy access to scientific communities in nearby London and major provincial cities, produced large numbers of "scientifically aware" engineers.

Overall, the close proximity of European mining schools—and in relative terms, the mining districts themselves—to centres of advanced scientific learning, gave Europeans an advantage in exploiting science for the resolution problems beyond their established "mechanical" traditions. In this respect, the different resource balance in Europe—relatively more labour, but fewer resources—encouraged scientists there to address resource saving problems with more vigour than their American colleagues. Given the direction of the development of international mining at the time, with its increasing emphasis on working lower-grade and more complex ores, this circumstance was most likely to point Europeans in the direction of the future, and to permit them to generate the most useful and effective of the new technologies.[34]

The Effect of External Economies

The pressures for technological change and advancement in American mines were not only dulled by the initial richness and ease of working of their ore deposits, but also by a series of external economies which reduced or held down costs. The introduction of cheap Chinese labour into California from the 1840s undoubtedly reduced working costs and helped to sustain labour-intensive methods, much as it did in South Africa during the first decade of the twentieth century.

More important, and wider and more sustained in its impact, was the coming of the railroad and the progressive lowering of transportation costs—particularly for fuel in, and for ore and metal out. This innovation provided a continuous flow of savings for even the most technologically conservative and under-capitalised operations. Within a year of its opening, the Virginia and Truckee railroad reduced the cost of freighting goods to and from the Comstock mines by nearly 50 percent, making economically viable the milling of ores previously considered too poor to process. Looking back on the 1870s, Clarence King concluded that "the two most important factors in the development of the precious metal industry during the decade have been the extension of the railway systems and the introduction of coal as a fuel throughout a portion of the mining regions of the West."

In his analysis of the impact of railways across the border in Mexico, historian Marvin Bernstein offers a more detailed explanation:

> Railroads aided mining from their very inception. They opened remote sectors; reduced freight charges on ore and supplies; made possible the introduction of large and heavy machinery into remote areas; tapped a hinterland from which the large smelters could draw even low-grade ore; helped solve the fuel problem by making possible the opening of a coal mining industry and the importation of American and British coal; and, finally, they cheapened both the cost of exporting mineral products and importing material from abroad.[35]

The Culture of Technological Conservatism

More controversially, it could be suggested that American mining districts developed an endemic cultural conservatism, re-enforced by institutional rigidities, which actively opposed technological change—a charge more commonly levelled at British industry than the American. Several authors have noticed that the technological evolution of western mining districts often occurred in phases. New districts often presented new technological problems in the working and processing of their ores. In the rush to grab profits, mines frequently adopted innovations based on unsound mechanical and scientific principles and that resulted in considerable losses. James Fell has referred to the difficulties and losses inflicted on the early Colorado gold industry by the "process men" and their entirely useless "desulphurizing" equipment.

The losses engendered by such experimentation and over-enthusiasm tended to produce a conservative reaction to future innovation and a cautious emphasis on well-proven machinery and techniques. A similar progression in the financial development of mining districts tended to reinforce this cycle. Rickard's observations on the opening of the Comstock provide a good example. Its explosive early development "did more harm than good to legitimate mining; it encouraged the idea of the sudden acquisition of wealth without work, of finding ore without systematic search. . . . The orgy of gambling, trickery and extravagance dishonoured a basic industry and drew into its ranks of honest workers, skilled engineers and sagacious managers, a motley crew of cheats, rogues and swindlers."

Once that latter group had left or been driven from the industry, and it settled into a more mature stage of development, control usually devolved to a more practical and "rule of thumb" group. They emphasised technological simplicity and the need to minimise the requirement for external capital. Such prejudice was encouraged by western mining law, which raised the constant prospect of being dispossessed by neighbours who could prove that they were working the "main ledge;" and by the practical reality in many districts that deposits pinched out at depth, making constant movement to new shallow, easily worked deposits a more profitable strategy than development at depth. Thus, alongside a few large and well-managed mines that provided beacons of best practice and acted as "outposts of modernity," existed much larger numbers of small- to medium-sized operations that continued to employ method "matching the most primitive anywhere."[36]

Labour Resistance

Even in the larger workings, with innovative owners and managers, labour often acted as a bulwark against change and mechanisation. Miners perceived the principal underground technologies developed in the second half of the nineteenth century—mechanical drills and chemical explosives—as a direct challenge to their traditional skills and independence. Above all, they saw the diversity of their occupation being undermined through a process of technological job fragmentation, in which a once wide range of activities became progressively focused on a narrowing range of simple "machine-minding" tasks.

Such innovations accordingly met with strong resistance nearly everywhere. In California, miners strongly opposed the introduction of "giant powder" in the 1860s and early 1870s, and the introduction of new drills in the Coeur d'Alene district of Idaho played a significant part in the violent labour troubles of the 1890s. Where modernisation was achieved more peacefully, it was often at the expense of costly managerial concessions, such as the agreement not to employ cheap Chinese labour on the Comstock, and the maintenance of traditional labour contract systems in the Keweenaw mines in the 1880s and 90s. In Europe, with its declining metal-mining industries and over-crowded labour markets, such resistance was far less effective. In Cornwall, strikes were rare and were mainly concerned with resisting the ever-downward pressure on wage rates as copper and tin prices fell.[37]

The Influence of European Labor and Management

While Europeans were being forced to pioneer new techniques and methods at home, they also had a predisposition to conservatism which the easier geological conditions of America and many other frontier areas allowed them to indulge. This was true, in varying degrees, of all of the world's developing mining districts in the late nineteenth century, but tradition was longer established and more entrenched in some of the strategic sectors of western mining. In the early years of California and the Comstock, European influence was particularly strong because of absolute numbers, while later, when more American miners came into the industry, it owed its existence to strategic placement in managerial hierarchies.

The 1860 Census records show that nearly forty thousand of the passengers arriving in the United States between 1820 and 1860 gave their occupation as miner, and they no doubt tended to congregate in areas where the domestic population was as yet very low. In 1870, when the main California gold rush was long past it peak, the number of miners in the state born in the British Isles and Germany amounted to more than half of those native born. In gold mining centres, such as Nevada County and Placer County, the proportion of all foreign born was as high as 80 to 85 percent of that of the domestic population. Across the Sierras, in Nevada, which was still in an earlier stage of development, the number of miners from the British Isles and Germany actually outnumbered those domestic born. However, the foreign domination was at its highest in the early development of the Michigan copper district. In 1870, over 90 percent of miners working there came from northwestern Europe, over 70 percent from the British Isles alone.

Even in the 1880s, Clarence King could observe that in the western mining districts "the resident population is usually scanty and dependent on the mines rather than self-sustaining or tributary to them" and that most of the actual underground mining operations—the drilling, blasting and picking of the ore—were left to Cornish and Irish miners. Native-born Americans confined themselves to related occupations, such as engine-driver, rope-, pump- and timber-man, machinist, and millman. Under such conditions, it was not so much an issue of the foreign born immigrants being assimilated by the native population, as foreign cultural "imperialism" making an equal mark on local practice and evolving traditions.[38]

Even when the number of European-trained miners began to diminish as a proportion of the total population in mining districts, they continued to exercise a highly strategic managerial influence in the choice of technologies. Historian Larry Lankton has concluded that while Americans became the financial managers of the mines of the Keweenaw as the chief clerks or agents, Cornish dominated the senior engineering posts as the mine or surface captains.

Even if mine owners distrusted the close relations that these middle managers had with the working miners from whose ranks they had risen, they often had little alternative than to employ them. As Spence has shown, America's sixteen mining schools and university mine engineering faculties together produced fewer than nine hundred graduates by 1892; this to serve the country's tens of thousands of mineral workings, while many of these graduates were lured away from the industry into railroad construction, government service, or foreign employment.[39]

The influence of the Cornish, however, was guaranteed by more than numbers and availability alone. They had been trained in what had been one of the world's most technologically advanced mining districts; they shared a common cultural and language background with American-born labourers and mine owners; and they were aware not simply of the technical problems of mining, but also of the complex managerial issues involved.

In the last respect, they held an advantage over other, more technically trained European mining engineers, such as the Germans, in being familiar with free-enterprise, minimal-investment, quick-return mining operations, rather than the more carefully planned, longer-term projects favoured in countries where mining was state owned and bureaucratically controlled. The Cornish had both the skills and the managerial pre-disposition for the kind of "smash-and-grab," resource-rich operations favoured in the western economic and cultural environment.

Whatever the reasons for their predominance, the Cornish certainly placed an indelible stamp on the industry. In particular, their empirical "apprenticeship trained" and "shop culture" background reinforced the American predisposition to favour the "practical," the rule-of-thumb, the "if-it-ain't-broke-don't-fix-it" school of technology. While such practical men no doubt made a major contribution to the efficient exploitation of western mines during the third quarter of the nineteenth century, by the 1880s, and certainly the 1890s, they were falling increasingly behind the times. The era of mechanical mining technology was coming to an end and the future was increasingly with the new science-based techniques. Cornish mining engineers, at home and abroad, were in their technological dotage and epitomised what was wrong with British technology generally at the end of the nineteenth century. They had neither the desire nor the means to adjust easily to this new world.[40]

As we have seen, this situation was not confined to America alone. In mining districts everywhere, particularly in those of the British Empire, "apprenticeship-trained" mine managers and engineers also formed a strong majority. Jan Todd makes many of the same points about poorly educated mining engineers and conservative and anti-scientific prejudices in her recent study of gold mining in Australia. If this was so, how were *some* of the companies mining in Australasia and South Africa able to be so innovative with new scientific technology?[41]

The answer is probably to be found in the *relative* availability of theoretically trained engineers. London speculators, who financed most British large-scale overseas mining enterprise, were usually not themselves previously experienced in metal mining, and relied on the services of expert managerial consultancies—such as John Taylor and Sons and Bewick, Moreing, and Co.—to direct their enterprises. Those consultancies could and did hire the best personnel they could find, and were always open to suggestions on how to tackle new problems and find new solutions to old difficulties.[42]

This was a very different situation from that pertaining in most relatively small western mines, where practically experienced, "hands-on" owners controlled production directly and commonly had neither the knowledge nor the inclination to experiment with new techniques. These organisational differences were reinforced by the relative supply of trained mining engineers. In Britain, a handful of mining schools produced well over eight hundred graduate engineers and metallurgists between 1870 and 1910—much less than America but far more than could be absorbed by the Kingdom's small and rapidly shrinking domestic metal-mining industry. This number was further augmented by the graduates of mining schools in the colonies themselves, and by the recruitment of foreign-trained personnel, as discussed above.[43]

There is at least circumstantial evidence, therefore, that in the critical years of technical change between the late 1880s and the early 1910s the availability and employment of well-trained and scientifically versed mine managers may well have been particularly low in western American mining districts, and that their role in the modernisation of the industry's technology suffered as a consequence. It was only when the output of American mining schools increased significantly in the ensuing decades that a new generation of managers finally replaced those trained in the old practical European traditions, and American mines emerged as the pioneers of a new generation of technologies.[44]

Conclusion

Numerous rebuttals and responses can no doubt be drawn from this analysis, but one clear thread binds them all together: resource abundance undermines the drive for technological excellence. Those who must, do; those who have choices usually exercise them. But perhaps this is a simple truism of all technological history.

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Notes:

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[15] See: Ihlseng and Wilson, *Manual of Mining*, 166; Marvin D. Bernstein, *The Mexican Mining Industry 1890-1950: A Study of the Interaction of Politics, Economics and Technology* (New York, 1964), 42; Bureau of Mines: Special Reports, 1902: *Mines and Quarries* (Washington, D.C., 1905), 476.

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