Volume Title: The Mining Industries, 1899-1939: A Study of Output, Employment, and Productivity

Volume Author/Editor: Harold Barger and Sam H. Schurr

Volume Publisher: NBER

Volume ISBN: 0-87014-042-6

Volume URL: http://www.nber.org/books/barg44-1

Publication Date: 1944

Chapter Title: The Origins of Modern Mining Methods

Chapter Author: Harold Barger, Sam H. Schurr

Chapter URL: http://www.nber.org/chapters/c6320

Chapter pages in book: (p. 97 - 116)

Part Two

Technological Change

"In order to mine the ore we must gain access to it, then we must break it down without mixing it with waste rock unnecessarily, and finally we must transport the valuable mineralized material to the surface. . . . Everywhere and for all time, the essence of mining is the same; change occurs only in the way of doing these simple, necessary things; and the particular way of doing them is determined by what happens to be the state of knowledge and the physical means available at a given time and place." C. E. JULIHN

Chapter 5

The Origins of Modern Mining Methods [1]

IF WE ARE to interpret intelligently the advances in productivity reported in the preceding chapter, we must acquire at least the indispensable minimum of information on technological developments in mining. There is much that is common to the methods of the different industries we study here, and innovations have frequently been carried over from one branch to another. For this reason it is convenient first to sketch the technological picture for mining as a whole, before we turn, in Chapters 8 through 13, to the relation between productivity trends and technological change in the more important individual industries.

There are many differences between contemporary American mining and its earlier counterpart. The industry started as a surface operation in which individuals, for the most part working independently, exploited rich outcroppings of coal or metallic ore.[2] It has evolved, with the passage of time, into the large scale, systematic exploitation of low grade mineral deposits, both underground and on the surface. Yet this change, so radical in scope, has taken place almost entirely since the middle of the nineteenth century.

This change, and the technological revolution which accompanied it, have affected the various branches of mining in greatly differing degree. It is in metal mining that the transition from the earlier small scale exploitation of rich mineral pockets to the large scale nonselective methods of today has proceeded farthest. Moreover, many problems were encountered first in this field, and their solutions later adapted to other types of mining. Accordingly, we shall begin with a sketch of technological changes in the mining of metallic ores, and then briefly review the history

[1] The scope of this and the two succeeding chapters in Part Two is confined to the technology of the mining (including ore dressing) and quarrying of solid minerals. We do not treat here the technological aspects of petroleum and natural gas production, since they are discussed separately in Chapter 10.

[2] For example, much of the copper mined during the eighteenth century was obtained in native form and did not even have to be smelted.

of coal mining. In Chapter 6 we shall investigate more particularly the forms which mechanization has taken in underground and open cut mining, and in stone quarrying. In Chapter 7 will be found a brief description of the methods employed in dressing and concentrating the mineral product, especially in the case of metallic ores, after it has been mined.

MINING METHODS BEFORE 1899: METALLIC ORES

Descriptions of mining operations in this country prior to about 1850 uniformly report a very primitive type of endeavor. Gold, because of the unique geological character of its deposits, was more important in this early period of mining than the more common metals, including silver.[3] The surface mining of gold was a fairly simple business. The itinerant placer miner, who carried his own pick, shovel and pan, merely scooped up the gold-bearing gravel, washed it, and pocketed the residue, which was a relatively pure product requiring no further processing. Although with the passage of years his tools became somewhat more elaborate—for example, he acquired several devices to replace or supplement the pan in order to insure a more efficient recovery of fine gold particles[4]—modern small scale placer mining is still very much like that of a century or more ago.

Vein or quartz mining of gold developed from these simple beginnings. Quartz mining originally consisted of the exploitation of surface outcroppings which could easily be worked. The veins were inevitably followed somewhat deeper and operations on such deposits must soon have taken the form of open pits which

[3] Gold mining usually takes precedence in new regions because gold is very often found in the native state in deposits from which it may be recovered with very crude devices. No reduction process is necessary to free the metal. In addition, gold is so valuable that exploitation is possible in remote regions since the product, which is low in bulk in relation to its worth, can easily repay the otherwise prohibitive costs of primitive transportation.

[4] Among these devices were boxes which sloped gently and were mounted on rockers. The gold-bearing dirt was shoveled into the box (although perhaps first passed through a screen) and the rocking hastened the separation of the barren rock and its washing away. This device was later improved by transverse riffles or partitions which retained a larger percentage of the gold at the bottom of the box. (T. A. Rickard, *A History of American Mining*, McGraw-Hill, 1932, pp. 29-31; see also James H. Collins, "Mining Copper and the Nobler Metals" in Waldemar Kaempffert [ed.], *A Popular History of American Invention*, Scribner's, 1924, Vol. II, pp. 55-60.) Later improvements in recovery effected by the use of mercury and the amalgamation process are discussed in Chapter 7 below.

the miner attempted to work in the same manner as the familiar placers.[5]

Surface operations were by no means confined to gold mining. In the early workings of other minerals the tendency was also to proceed from the surface down, but this miniature open pit operation lacked all the economic and engineering features of contemporary large scale surface mining. Metal mining as practiced during the first half of the nineteenth century was a simple art, easily mastered. Often it consisted of nothing more than the gathering of loose outcrops. Or, in its more complex forms it might require the digging of trenches from which ore could be carried up inclined ways, as observed in Mississippi lead mining about 1820;[6] also drifting for some distance into the sidehills.[7] The men engaged in these activities could hardly be looked upon as skilled miners. Frequently they were primarily farmers; indeed, in the early days in the South, farming and small scale mining were often jointly pursued.[8] In any case, they were men without the technical experience one would then have found, for instance, among Cornish miners in England.[9]

Mining in this country was almost universally in the hands of individuals who, using simple tools and common sense, were able to obtain a mineral product easily convertible into cash. Even the extraction of the metal from its ore was largely performed by the miners themselves, and this was true not only of gold, which was relatively simple to recover, but even of lead, which required a pyrometallurgical operation.[10] The backward state of the arts of mining and metallurgy in the United States was actually attributable to the fact that rich mineral outcrops were readily available. Thus it was economically feasible to make a technically ineffi-

[5] Isaac Hourwich, writing in the 1902 Census, states: "The most natural method which suggested itself to the human mind for dealing with the gold-bearing rock was to reduce it to the same state in which the alluvial [placer] gold deposits were found and to separate the disseminated particles of gold from the pulverized mass by the familiar method of washing" (U. S. Bureau of the Census, *Special Reports*, "Mines and Quarries, 1902," p. 575).

[6] Rickard, *op. cit.*, p. 160. The author here refers to the observations of Schoolcraft, an Indian agent of the Federal government, who visited the district.

[7] "Mines and Quarries, 1902," p. 460.

[8] Walter R. Crane, *Gold and Silver* (John Wiley and Sons, 1908), p. 343.

[9] This was less true of coal mining, however, for many of the early coal miners had learned their trade in Europe: see Carter Goodrich, *The Miner's Freedom* (Marshall Jones, Boston, 1925).

[10] Hourwich points out that up until the first quarter of the nineteenth century lead ore was crudely smelted by the miner ("Mines and Quarries, 1902," pp. 460-61).

cient recovery of metal from ore, or to abandon a rich operation of slight depth because water was encountered and could not be dealt with.[11] Pumps were available, but pumps required capital, and neither the demand for mineral raw material nor the imminent exhaustion of workings which did not require pumping had as yet called forth such investment. Similarly, the sinking of shafts was rare; where shafts were used the ore was raised by horse whim or windlass.[12] Power for all purposes was still provided by human muscle or brute force. Steam was not yet in common use, although in England during the eighteenth century it had been generally employed to actuate pumps. Even as late as about 1880 the following conditions seem to have prevailed in the Mississippi Valley lead district:

> Some storekeeper, farmer, or local capitalist furnished the small amount of money needed for tools; and the men who worked in the ground in winter usually engaged in farm work during the summer. The ore was generally raised to the surface by a windlass, and cleaned by hand with a "pickawee" hammer, or crushed with a "bucking iron" on a flat stone, or by an itinerant horsepower crusher, and was concentrated by sluicing and hand jigging.[13]

Important changes had, however, taken place before 1880, even though they had not permeated the entire structure of the metal mining industry. And as we might expect, gold and silver were in the vanguard. In placer mining the older methods of scooping and washing gravel began to be partially superseded by hydraulic mining around 1853. This advance was stimulated by conditions of climate and topography. Powerful streams of water were utilized to wash gravel banks down into trenches (ground sluices) in which recovery of the gold was effected. The earliest devices must have consisted of ordinary hose with an improvised nozzle (sometimes merely a tapering wooden box) attached to it.[14] In any case the method had a remarkable growth until conflict with California farming interests resulted in legislation virtually prohibiting the practice.[15] During the period of its greatest de-

[11] "Mines and Quarries, 1902," p. 460.
[12] Crane, *op. cit.*, p. 349.
[13] "Mines and Quarries, 1902," pp. 461-62.
[14] Crane, *op. cit.*, p. 344.
[15] The tailings from these operations were discharged into streams which, in turn, deposited them along their course, causing damage to adjacent farm lands ("Mines and Quarries, 1902," p. 572).

velopment (from about 1853 to 1875) huge sums of money are believed to have been invested in hydraulic equipment, and in the construction of ditches and canals for carrying water to centers of mining activity.[16] The chief result lay in the province of industrial organization with a shift from individual enterprise to operations of large companies, which alone were able to carry through the work on a sufficiently broad scale.[17] Placering did not die with the restrictions on hydraulic mining but developed in the direction of dredging—a technique utilized to tap deep-lying auriferous gravels. However, this is a development which began at about the turn of the century[18] and it was, at that time, no longer unique as a manifestation of large scale enterprise.

Of far greater significance in the evolution of mining technology was the development of a silver mining industry with the discovery of the fabulous Comstock lode near Virginia City, Nevada, in 1859. In broad terms it may be said that silver mining (beginning at Comstock) ended the poor man's day in mining and ushered in the era of the financier and the engineer.[19] Crude hand devices and common sense, so effective in the past, were now unable to cope with the depth and complexity of the vast silver workings, which required the adoption of methods hitherto unfamiliar in this country. Of these the most important was probably the system of square-set timbering, whereby timbers in rectangular sets replaced the ore as it was removed, so that the spaces between the timbers could be filled with waste rock to increase the strength of the support.[20] This method permitted the exploitation of large ore bodies with weak walls, which could not be handled under the older system of open stopes, i.e., stopes with only occasional artificial supports, if any.[21] Because it made possible the development of other large ore bodies, including the great copper

[16] Crane, *op. cit.*, pp. 345, 347.

[17] *Ibid.*, p. 347.

[18] "Mines and Quarries, 1902," p. 573.

[19] A succinct expression of the financial requirements of silver mining is found in an old Mexican adage, "It takes a gold mine to open a silver mine."

[20] E. D. Gardner, C. H. Johnson and B. S. Butler, "Copper Mining in North America," *Bulletin 405* (U. S. Bureau of Mines, 1938), pp. 114-15. In reviewing the present manuscript, Professor Read observed that square-set mining was the first important application of the principles of engineering directly to mining, as contrasted with the adaptation to underground use of techniques originally developed elsewhere.

[21] C. F. Jackson and J. H. Hedges, "Metal Mining Practice," *Bulletin 419* (U. S. Bureau of Mines, 1939), pp. 224-27. A stope is merely a room in which ore is mined.

lodes at Butte, Montana,[22] square-set timbering occupies an honored position in the development of the art of mining.[23] It still occupies an important place in those underground metal mines in which the newer shrinkage and caving methods (discussed below) cannot be employed.

Technology was forced, almost for the first time in this country, to adjust itself to new and unfamiliar geological conditions. Not only was the finest European machinery introduced, but mechanical and other innovations made Comstock for a time the "mining school of the world." [24] It may almost be said that the practicability of deep metal mining was demonstrated for the first time on the Comstock lode.

The further development of underground metal mining hinged on a number of factors which were coming into operation in the latter half of the nineteenth century. One was the constant expansion of the railroad system, now beginning to reach into regions hitherto virtually inaccessible. In many regions known to be rich in minerals, it was not feasible to undertake organized exploitation until the coming of the railroad lowered both the cost of materials needed for mining and the cost of marketing the mineral obtained. The influence of this factor is nowhere more clearly seen than in the opening of the western districts producing argentiferous lead ores. The existence of these deposits had been known to those who had earlier worked the same districts for placer gold, but large scale exploitation awaited the development of the railroads.[25] The expansion of the railroad network was bound up with the growth of the nation and the expanding industrialism which marked the post-Civil War period in American history. And it was the new industrialism, in turn, which created the demand for mineral raw materials. The need for metals could no longer be met by skimming the rich surface layer from mineral deposits. Mining had to be carried to greater and greater depths, and fortunately the initial step in this direction had already been taken.

[22] Robert M. LaFollette (ed.), *The Making of America*, Vol. 6 (Morris, Chicago, 1906), p. 27.

[23] Gardner, Johnson and Butler, *op. cit.*, p. 115.

[24] Crane, *op. cit.*, p. 350; see also LaFollette, *op. cit.*, p. 27.

[25] F. G. Tryon and Margaret H. Schoenfeld, "Mineral and Power Resources" in *Recent Social Trends* (McGraw-Hill, 1933), Vol. I, p. 66; also "Mines and Quarries, 1902," p. 460.

MINING METHODS BEFORE 1899: COAL

Up to this point the discussion has been confined to the mining of metallic ores. We undertake a separate treatment of coal mining because the chronology of its technological development differs from that of metal mining. The extraction of anthracite in Pennsylvania reached a higher stage of technical efficiency during the first half of the nineteenth century than did other forms of mining. During the latter half of the century, however, the technology of metal mining advanced at so rapid a rate that it overtook coal mining, and at some point about midway in this period the two lines of development tended to converge. Thereafter metal mining technology led the field, but a pattern of development more or less common to both coal and metals can be traced.

An account of early nineteenth century coal mining would, in its significant aspects, read remarkably like the story of metal mining some decades later. Primitive tools, unskilled workmen, and lack of organized exploitation are as prominent here as they were in metal mining.[26] This resemblance is not surprising when we consider that the underlying factors were similar: in both cases the combination of easily accessible deposits and comparatively restricted demand explain the backward state of production techniques. But the point at which these circumstances ceased to apply was reached earlier in anthracite coal than in metals. Moreover, among the immigrants to this country there were many who were familiar with European coal mining techniques. As a result the utilization of more advanced methods emerged at an earlier date in coal than in metal mining.

Steam power was first employed in the mining of American anthracite as early as 1836. In that year a mine was sunk below the water level, a venture which depended on mechanized pumping.[27] Prior to that time all mines had been worked by tunneling from the water level upward,[28] but new deposits which lent themselves

[26] Peter Roberts, *The Anthracite Coal Industry* (Macmillan, 1901), p. 17.

[27] Eli Bowen, *Coal and the Coal Trade* (Peterson, Philadelphia, 1862), p. 27. Apparently the mining of bituminous coal continued for some time longer without benefit of steam powered pumps.

[28] Roberts, *op. cit.*, p. 18.

to natural drainage were becoming rarer.[29] The number of mines sunk below water level increased steadily; by about 1850 they added up to a fairly large segment of the anthracite industry—a segment in which steam power was essential to operations.[30] At about that time, too, the breaker was first used to prepare anthracite for the market, and steam power motivated the rolls and screens.[31]

Mechanical progress was accompanied by changes in the organization of the anthracite industry. The fields were orginally divided into small tracts of land that were operated successfully so long as simple production techniques were adequate. But as operations became more difficult and as expensive equipment became necessary, many small operators were unable to continue independently. Consolidation of small holdings into the hands of large companies soon began to spread, yet as late as the 1860's there existed no company able to organize production on a scale sufficiently large to utilize the most advanced production techniques of the day. This is clear from the writings of Eli Bowen, who argued that the universal use of slopes rather than perpendicular shafts for deep anthracite mining was retarding the development of the industry. The suggested remedy was to "organize companies with large capital, to sink enormously deep and permanent shafts." [32]

While anthracite production techniques moved ahead, bituminous coal remained for some time at a comparatively low technological level.[33] Resource conditions in bituminous fields were such that coal was easily worked by methods familiar in Europe.[34]

29 However, it is noteworthy that the continued availability, even today, of small shallow deposits in the anthracite fields of Southern Pennsylvania has been a factor facilitating bootlegging operations (Commonwealth of Pennsylvania, *Report of the Anthracite Coal Industry Commission,* Harrisburg, 1938, p. 48). See also Chapter 9 below.

30 Bowen, *op. cit.,* p. 27.

31 Dever C. Ashmead, "How Greater Depth and Reduced Thickness of Coal Have Intensified Lackawanna Mine Problems," *Coal Age,* Vol. 23, pp. 324-25 (February 22, 1923). The preparation of coal for the market is discussed below in Chapter 7.

32 Bowen, *op. cit.,* p. 31.

33 However, the comparative backwardness of the bituminous industry was later to disappear. For when coal cutting machines and other mechanical devices were introduced into the bituminous fields, they were found unsuitable for mining anthracite. See below, Chapter 6, p. 124; and Chapter 8, Table 15.

34 Shallow deposits and opportunities for natural drainage in late nineteenth century bituminous coal mining appear to have been peculiar to this country. Thus Jevons writes of Britain: "We have no extensive seams of coal now which can compare with those above described [i.e. in the United States] . . . four or five centuries

Technological adjustment to a changed geological environment, as in anthracite and metal mining, was not forced upon the industry until later in the century.[35] When the problems of deep development did arise, the result was mechanization of auxiliary functions such as pumping and ventilation. Thus by the end of the nineteenth century bituminous coal, anthracite and metal mining had developed a technology which—despite individual variations—had certain distinguishing features common to all three industries. We may now turn to a consideration of the characteristics of late nineteenth century mining.

METAL MINING TECHNOLOGY IN 1899

The years following the inauguration of deep mining were marked by the discovery and exploitation of new mineral deposits, in many of which problems of deep development were encountered for the first time. By the opening of our period production of minerals came largely from these new underground mines.[36] Methods of shaft sinking, underground tunneling, and roof support had reached a high level of efficiency. Mechanical power, commonly steam, was in use for the vital auxiliary functions of hoisting, pumping and ventilation.

By now, too, the miner had developed into a highly skilled craftsman with a clearly defined function. The prodigality with which his predecessor had exploited rich deposits was, of neces-

ago it is supposed there were seams on the banks of the Tyne, and at Whitehaven, which could be worked by natural drainage. . . . But shallow coal has necessarily almost disappeared in England" (W. Stanley Jevons, *The Coal Question,* ed. by A. W. Flux, Macmillan, London, 1906, p. 342). The continued existence of shallow seams in this country must be credited partly to a comparatively greater initial abundance of such seams in relation to early rates of fuel consumption. It may also have been due in part to the use of wood for firing locomotives and of charcoal for smelting iron until a much later date than was possible in England, whose forests had all but disappeared by the end of the seventeenth century. It is worth noting, too, that prior to 1860 there was still a large demand by blacksmiths and other small scale fabricators for charcoal iron: they appear to have preferred this product because of the ease with which it could be fashioned for a wide variety of different uses. See Louis C. Hunter, "Influence of the Market upon Technique in the Iron Industry in Western Pennsylvania up to 1860," *Journal of Economic and Business History,* Vol. I, No. 2 (1929), pp. 241-81.

35 Indeed, some would say that changing geological conditions have been less important in forcing mechanization than have rising wage rates.

36 The leading exception was the large scale open cut exploitation of the Mesabi iron ore range, on which operations had begun in 1892. This operation introduced mechanical methods which did not become general until after 1899. The mechanization of large scale open cut mining is discussed below in Chapter 6.

sity, replaced by great care in working the mineralized area, for the miner was charged with the responsibility of extracting as much of the mineral with as little loss in waste as possible. In addition, the job of timbering for support and of maintaining the working face was his. In spite of the larger scale on which mining was now conducted, the actual separation of the mineral from the ground was still predominantly a hand operation. This was true in spite of the striking mechanical advances which had been made in the auxiliary functions of mining. In metal mining, for example, by 1899 compressed air drills were used for tunneling to gain access to the ore, but hand drilling and hand picking were still needed for mining the ore itself. And although dynamite had replaced black powder, and thereby increased the efficiency and safety of blasting, it was still utilized sparingly in mining operations. Commonly its use was confined to breaking the rock in approaching the ore body; often in winning the ore itself blasting was entirely forbidden.[37]

This preference for methods apparently less efficient than others that were readily available was the direct result of the rationale of mining technology of that period. A miner using hand tools will account for a much smaller tonnage per shift than he would if he were using mechanized tools, but he can produce a higher grade of product because he can exercise care in selection and avoid waste. Whether the mine operator will choose tonnage or quality is basically an economic decision, but this decision itself is shaped by external factors. On the one hand are geological conditions, such as the richness of the ore. When a high grade ore body is worked, the mine may be unable to afford such mineral losses as would accrue, for example, through the introduction of mechanical breaking. As the ore declines in grade, however, such losses may be counterbalanced by the increased tonnage made possible through mechanization, coupled with subsequent concentration. The basic decision rests upon technological factors which determine the minimum grade of material that can be sold or utilized in further processing. If a metallic ore, for instance, is to go directly from the mine to the smelter, without intermediate processing, the grade of ore is of great importance:

[37] C. E. Julihn, "Copper: An Example of Advancing Technology and the Utilization of Low Grade Ores," in *Mineral Economics,* ed. by F. G. Tryon and E. C. Eckel (McGraw-Hill, 1932), pp. 127-28.

for smelting involves difficult and expensive pyrometallurgical processes which are very sensitive to the amount and character of the waste in which the metal is embedded. If, on the other hand, waste can be eliminated before shipment to the smelter, and particularly if the devices for this purpose are designed to operate cheaply and on a large scale, then a much lower grade of ore may profitably be mined. In the latter case an additional step in the production process will have been interposed between mining proper and smelting—a step which takes over a function previously performed by the miner himself. This is called beneficiating, and will be discussed below (Chapter 7).

Until close to the very end of the nineteenth century the grade of metallic ores worked was still high and the efficiency of bulk processes of mineral enrichment or beneficiation was low—circumstances which account for the popularity of the highly selective methods of hand mining already described. The first deviations from this type of mining, as on the Mesabi iron ore range, occurred late in the century. They may be considered to have ushered in the modern era of mineral exploitation. By 1899 the impact of these changes was beginning to be felt, but their full development belongs to the subsequent period.

THE DEVELOPMENT OF NONSELECTIVE METAL MINING

The changes we associate with the transition to modern methods of metal mining first appeared in the extraction of copper ores. The emergence of modern methods of bulk or nonselective mining (as opposed to the older, selective methods) did not involve a distinct act of invention, but occurred rather gradually. In many mines the "pay streak," i.e. the richer part of the deposit from which production had so far been derived, approached exhaustion, or at least reached the stage where it alone was not sufficient for full utilization of the mine and mill facilities. Lower grades of ore were available, and their production involved only the additional cost of breaking, loading and transportation; the overhead costs associated with the auxiliary functions of pumping, hoisting and ventilation could, moreover, be spread over a larger production. Since the ores were of low grade they could be mined with less care, so that drilling and heavy blasting of the ore—which were avoided in the pay streak—could safely be applied. The results achieved were sufficient proof of the workability of low grade ores when mechanized methods were used. In some cases tonnage of ore per man-shift under nonselective techniques equaled the tonnage per man-week achieved with selective methods. Thereafter nonselective mining spread rapidly in underground metal mines fully a decade before it made its spectacular debut on the surface in open cut copper mining.[38]

The first step in the abandonment of selective mining consisted of the mechanization of functions which it had previously been thought necessary to perform by hand.[39] Thus breaking might profitably be mechanized if the grade of ore were low. But the constantly increasing use of nonselective methods at the turn of the century was associated also with the development of new techniques for concentrating metallic ores.[40] These new techniques contributed to the decline in the importance of selective methods at underground nonferrous metal mines, and made low grade surface development possible.[41] The foundation of modern methods of mining copper, for example, rests upon mechanization, but their essence lies in the integration of mining with ore dressing. When mining engineers first realized that the ability to concentrate the mineral product rapidly and efficiently had altered the relative advantages of different mining methods, and when they turned to the task of finding that combination of mining method and beneficiating technique which would insure the most effective utilization of a given mineral deposit, then modern mining began to take shape.

It is not easy to select a particular event in the history of mining as the turning point in this respect. We can, however, notice certain crucial steps, perhaps the plainest of which was the decision to exploit the steam shovel for the mining of Mesabi iron ore. Here was a clear case where the application of a mining method, then distinctly novel, was determined by extensive planning and exploration prior to the opening of the field. It was found that the ore body was particularly well adapted to open cut

[38] See Julihn, *op. cit.*, pp. 128-30.

[39] A more systematic treatment of the mechanization of the mining process will be found in Chapter 6 below.

[40] These are described in Chapter 7 below.

[41] On the other hand, the mass mining of iron ore at first owed little to processing techniques, but resulted rather from the peculiar geology of the Mesabi range.

exploitation, and thus began a type of mining which has since shown considerable adaptability and growth.

This kind of mining reached its full development in the first open cut copper mine at Bingham, Utah, where still another basic step was taken. The men who developed the Utah property were faced with a situation which differed from that on the Mesabi range in one very significant respect. Steam shovel mining alone was not the key to the development of the ore body. What was essential, in addition, was a concentrating technique able to take the steam shovel product—which was of exceedingly low grade—and convert it into a higher grade material which could be smelted. In other words, the ore body could be worked only by the combination of low cost mining and a bulk beneficiating process able to extract metal from a relatively large proportion of rock. In open cut copper mining there now developed a completely articulated technology of mining and beneficiating. The function of producing a pure or clean mineral product was completely separated from the function of breaking and extracting the ore. Bulk processes were utilized for both operations, and, as a result, overall efficiency was increased.

From our present perspective, nonselective mining appears to have been the mining industry's version of the process of specialization of functions which was occurring simultaneously in other industries. Ever since the introduction of open cut copper mining, nonselective mining methods have come to dominate the American mineral industry. Although metal mining—particularly copper—has produced the most complete expression of nonselective technique, its use is by no means confined to this portion of the mineral industry. Coal mining has developed in the same direction;[42] even the minor nonmetallic industries have not remained unaffected.[43] The latter group has been characterized in recent years by "wider adoption of bulk mining instead of highly selective mining, now that means have been found to remove admixed impurities mechanically." [44] Nevertheless the applica-

[42] Willard E. Hotchkiss and others, *Bituminous-Coal Mining* (National Research Project, Philadelphia, 1939), p. 11.

[43] Oliver C. Ralston, "Flotation and Agglomerate Concentration of Nonmetallic Minerals," U. S. Bureau of Mines, Report of Investigations, No. 3397 (May 1938), p. 2.

[44] Paul M. Tyler and Oliver Bowles, "Nonmetallic Mineral Industries in 1939," Information Circular 7106 (U. S. Bureau of Mines, 1940), p. 3.

tion of such techniques has not been universal. In the quicksilver industry, for instance, mass mining is notably absent.[45]

The fashion in which nonselective techniques manifest themselves in individual mines is, in good part, determined by resource conditions. When these lend themselves to open cut exploitation, that method is utilized. But resource conditions do not remain constant; and, with the exhaustion of ore bodies lying near the surface, the recent trend toward this particular method may be reversed, and a return to underground mining occur.[46] This does not mean an end of mass mining, for similar techniques are already widely used in underground exploitation.

The traditional methods of underground metal mining—cut-and-fill, and stoping with much square-set timbering—were developed in an age of hand shovel loading and the selective mining of rich ores. Still used in many mines where conditions do not permit of mass exploitation, these older techniques have given way increasingly to methods which employ shrinkage and caving. These methods, some of which break and load the ore by gravity, are nonselective in character. When they are used serious efforts to differentiate grades of ore, or to separate mineral from waste, within the mine itself are abandoned, and these functions are transferred to milling equipment on the surface.

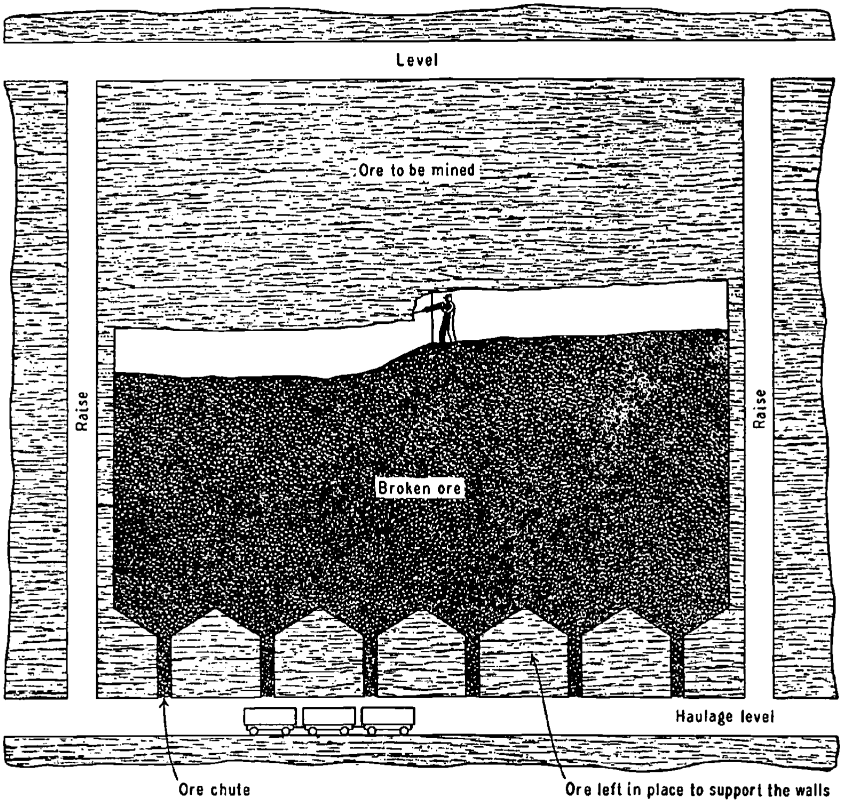
Perhaps the three most characteristic examples of these newer methods of underground metal mining are shrinkage stoping, sublevel caving and block caving.[47] The choice of one or another of these, or of a variant or combination of them, is determined by the nature of the ore body. We have space here only to notice their most essential features. Shrinkage stoping (Chart 33) involves the least departure from traditional practice, for the ore

[45] C. N. Schuette, "Quicksilver," *Bulletin 335* (U. S. Bureau of Mines, 1931), p. 26. By the standards of other types of metal mining, mercury ores are lean, but their large scale exploitation by mechanical methods has not so far proved feasible.

[46] See National Resources Committee, *Technological Trends and National Policy* (1937), pp. 162-63. A case in point is the United Verde mine in Arizona where surface deposits are practically exhausted but large amounts of copper remain to be mined by underground methods.

[47] The description which follows is largely based upon Robert Peele and John A. Church, *Mining Engineers' Handbook* (3rd ed., John Wiley, 1941); Robert S. Lewis, *Elements of Mining* (2nd ed., John Wiley, 1941), Chapter IX; A. B. Parsons, *The Porphyry Coppers* (American Institute of Mining and Metallurgical Engineers, 1933), Chapter XIX; and Y. S. Leong and others, *Copper Mining* (National Research Project, Philadelphia, 1940), Chapter IV. For a lucid and concise account of these and other methods, see Professor Lewis' article on "Mining, Metalliferous" in the *Encyclopaedia Britannica*, 14th ed.

Chart 33
METAL MINING METHODS: SHRINKAGE STOPING
Sectional Diagram

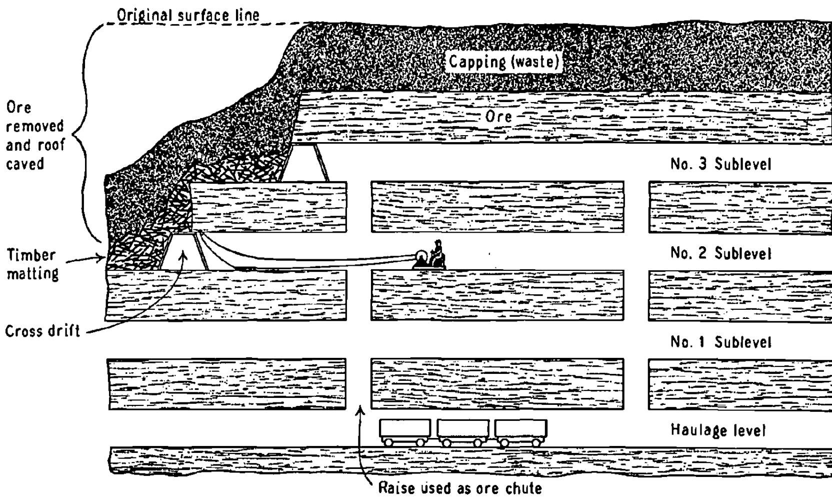


For source and notes see Appendix E

continues to be broken by drilling and blasting. Work proceeds upward as the miner stands on a floor composed of broken ore. The latter, since it occupies more space than the uncut mineral, must continually be drawn off through chutes to waiting cars below. As each section is mined out the remaining ore is drawn off. The method can be employed only where the walls are strong; its chief advantage over earlier practice is the use of gravity loading. Its nonselective character is shown by the fact that virtually the whole of the ore is removed, and no opportunity is given to the miner to prevent waste as well as ore from reaching the mine cars.

In sublevel caving (Chart 34) a number of sublevels are driven into the ore body at increasing vertical distances above the haulage level, and the ore remaining between the levels is mined from the top downward by caving. In this method, which is characteristic of underground iron mining in the Lake Superior region, gravity is used to break that part of the ore which is caved. Loading again takes place through a chute, but before this can occur

Chart 34
METAL MINING METHODS: SUBLEVEL CAVING
Sectional Diagram



For source and notes see Appendix E

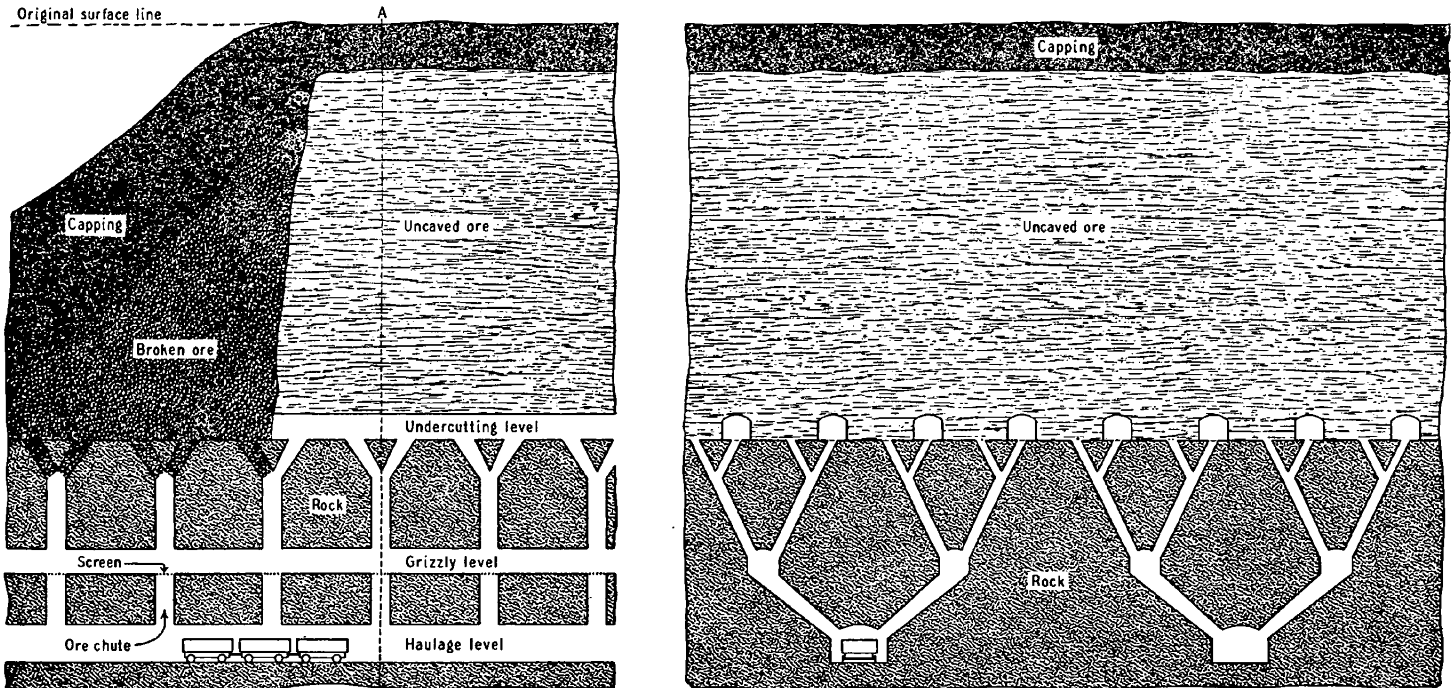
the ore must be trammed or scraped along the sublevel to the top of the chute. Sublevel caving is a development of a method known as top slicing, originally introduced in iron mining. In top slicing only the highest sublevel shown in Chart 34 is driven, and this is done immediately below the capping: mining proceeds downward, and the capping is allowed to cave.

The most advanced of the several techniques is block caving (Chart 35) in which the ore is broken and loaded almost entirely by gravity. A large mass of ore, perhaps 300 feet in height, is undercut except for supporting pillars. The latter are blasted away, so that the whole body of ore and overlying rock cave a short distance, in the course of which the ore is broken. As the ore is drawn off into mine cars through the chutes, the overlying rock

Chart 35

METAL MINING METHODS: BLOCK CAVING

Sectional Diagrams



Section on A—A

For source and notes see Appendix E

continues to cave, until all the ore has been removed. Block caving has found its widest application in underground copper mining, and has been said to represent "probably the most important advance in underground copper mining methods since the invention of square-setting." [48] Originally introduced in Utah in 1906 as a development of sublevel caving, block caving requires soft or fractured ores for success, but it can be used with ores of grade so low that other gravity methods will not pay. It resembles open cut mining in that all material in the mineralized area is removed, waste as well as metallic ore.[49]

It is clear that the two main characteristics of the transition to nonselective mining—whether underground or open pit—have been, first, a decline in the grade of ore mined, and second, an elaboration of techniques of ore concentration. Thus we have already seen that nonselective mining was originally fostered by the decline in the grade of material mined. It was the industry's good fortune to be able to make a virtue of necessity. For the new techniques became so efficient that it is now often worth while deliberately to sacrifice quality for quantity in the mining process, and to achieve the former later, during concentration. The absence of new discoveries has no doubt contributed to the decline in the grade, for example, of copper ore during the past forty years. It has been estimated that as much as one half of the present copper production of the United States comes from deposits that were known in 1900 but were not then worked because of their low metal content.[50] This is, of course, an extreme illustration, but undoubtedly the same type of change (although less in magnitude) has characterized other mineral industries.[51] Where nonselective, i.e. large scale, operations are feasible, and the material mined can readily be concentrated, the grade of the ore has ceased—within wide limits—to exert upon costs the dominant in-

[48] Gardner, Johnson and Butler, *op. cit.*, p. 115.

[49] Tryon and Schoenfeld, *op. cit.*, p. 68.

[50] Andrew V. Corry and O. E. Kiessling, *Grade of Ore* (National Research Project, Philadelphia, 1939), p. 84.

[51] In the words of Professor Bucky of the Columbia University School of Mines: "Within the realm of our experience it is evident that the finding of ore bodies is being subordinated to economic extraction . . . improved practices [have] continually made available the ore bodies which at one time were not economic" (*Engineering and Mining Journal*, August 1941, p. 113). Further specific instances of the utilization of lower grade material, more or less directly attributable to advances in ore dressing techniques, are cited in Chapter 7.

fluence it formerly exercised. Where operations lend themselves to mass exploitation, it may happen that low grade deposits can be worked more cheaply than higher grade deposits which cannot be thus exploited.[52]

It has been remarked, indeed, with reference to the newer techniques of large scale mining, that "The prospector stands aside; the engineer steps forward." [53] It might also be noted, and with almost equal validity, that the skilled miner stepped aside when the engineer stepped forward. For when the engineer was called upon to plan the large scale exploitation of minerals, the traditional technology based on the resourcefulness of the highly skilled individual miner began to fall apart. No longer does the success of the mining enterprise depend on the expertness with which the miner breaks the mineral and separates it from the waste; it is now a question of how well the engineer has designed mining and beneficiating operations on the basis of his geological data, and how carefully he has determined the geological structure and chemical nature of the ore deposits prior to the working out of suitable techniques.[54] This is patently true in open cut workings and of underground mines where caving methods are employed: here design is of the greatest importance. It is true also, if sometimes in lesser degree, of all mechanized mining, where maximum efficiency may depend on a reorientation of mining method to the facts of mechanization. Meanwhile, the skilled crafts-

[52] This point emerges very clearly in an exchange between Cornelius Kelley, president of the Anaconda Copper Company, and the chairman of the Temporary National Economic Committee (*Hearings*, Part 25, Washington, 1940, p. 13203):

Chairman: Of course it is common knowledge in mining regions that ore varies in content, that you have high-grade ore and low-grade ore, that ordinarily the high-grade ore may be produced at a low cost, and the low-grade ore is produced at a higher cost. That is true, is it not?

Mr. Kelley: No, sir.

Chairman: It is not? What is the fact?

Mr. Kelley: The fact is that the cheapest ore in the world is produced from the lower-grade ores where the character of the operation is such that it lends itself to great volume and mechanization. Those factors more than overcome a much higher grade of ore that has to be mined from a depth, transported underground and hoisted to the surface. Generally speaking, Senator, the lowest-cost copper is being produced from the lowest-grade ore.

[53] T. A. Rickard, "The Utah Copper Enterprise" (San Francisco, 1919), p. 9 (reprinted from *Mining and Scientific Press*, Vol. 117, December 28, 1918, p. 848).

[54] Walter H. Voskuil, *Minerals in Modern Industry* (John Wiley, 1930), p. 7. It is in exploratory drilling that churn drills, which allow the nature of the deposit to be determined, have been of such enormous importance.

man has given place to the machine tender. Here, too, the position of the skilled worker has been subject to the same influences that have been operative in other industries.[55]

[55] See Y. S. Leong and others, *Copper Mining* (National Research Project, Philadelphia, 1940), pp. 29-31. Even in coal mining, where craft traditions have survived best, similar tendencies have been at work: see Carter Goodrich, *The Miner's Freedom*, pp. 108-10.