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Chapter 6

The Mechanization of the Mining Process

As WITH OTHER less spectacular changes in the technique of extraction, the transition from selective to nonselective methods has involved a high degree of mechanization, both in the actual operation of winning the ore and in its subsequent processing. Although it has influenced other types of mining at numerous points, nonselective exploitation is primarily a characteristic of the metal mining industries—iron ore, copper, lead and zinc, and mixed metal mining. But mechanization is by no means confined to these industries. Even where—as in coal mining—resource conditions have not permitted a spectacular departure from older mining methods, mechanization has made striking advances. In many such mines the entire process, from drilling and blasting to loading and hauling, has been more or less completely mechanized. Such mechanization may be said to have produced a qualitative change in mining methods. When just one or two operations are mechanized, production is speeded but the method as a whole may remain essentially unchanged. As mechanization spreads, the integration of different processes, and the adjustment of the tempo of one to that of another, become more and more pressing, until eventually the whole interior of the mine may have to be redesigned.[1] In the case of many coal mines, when the last link in the chain of underground mechanization was forged with the introduction of mechanical loaders, a balanced cycle of operations became essential and many modifications of the traditional room-and-pillar method of mining were needed. In addition, the surface preparation plant assumed an increasingly important role, for once coal is loaded mechanically it can no longer be cleaned

[1] Albert L. Toenges, "Mining" in A. C. Fieldner and W. E. Rice, "Research and Progress in the Production and Use of Coal," Technical Paper No. 4 (National Resources Planning Board, 1941), p. 14. We shall find later that the apparent lag in bituminous and anthracite coal technology is in part attributable to the difficulty of redesigning these mines to accommodate new mechanical devices. This has been an outstanding cause of delay in the introduction of mechanical loading in particular. See below, pp. 124-29, and Chapters 8 and 9.

by the individual miner at the coal face. Changes of this kind in coal mining are less dramatic than those which accompanied the mechanization of copper and iron mines, but they are still considerable.

To the extent that mechanization involves a reorganization of mining methods, the mining industry alone may be credited with a substantial portion of its technological advance. We must not forget, however, that in the process of mechanization the mineral industry has been aided by technical advances achieved in other industries. Many of the early tools used in underground and open cut mining were originally devised for driving railroad tunnels,[2] and always the development of mining machinery has been dependent upon the "quality of construction materials such as alloy steels . . . and upon advances in the electrical and mechanical arts." [3] It is difficult, too, to overestimate the true importance of the development of electrically powered equipment, for without electricity "it would have been economically unfeasible, if not physically impossible, to mechanize many functions previously performed underground by hand labor or with animals" because of the difficulty of transmitting power by means of shafts, gears or belts to cramped underground workings.[4]

We must now examine in greater detail the forms mechanization has taken, both where nonselective methods are used and where resource conditions have not permitted their adoption. To do this it will be convenient first to consider underground mines, and thereafter to discuss open pit operations.

UNDERGROUND MINING

There are three major steps in the process of mining ore underground. They are: (1) breaking the ore; (2) loading the broken ore; and (3) transporting the ore from the working face to the surface. It is most convenient to sketch technological change in underground mining in terms of these three steps in the mining process, for aside from changes in mining method proper, technological improvements have consisted mainly of the mechaniza-

[2] James H. Collins, "Mining Copper and the Nobler Metals," in Waldemar Kaempffert (ed.), *A Popular History of American Invention* (Scribner's, 1924), Vol. II, p. 65.

[3] Toenges, *op. cit.*, p. 6.

[4] Nicholas Yaworski and others, *Iron Mining* (National Research Project, Philadelphia, 1940), p. 24.

tion of these functions. We shall discuss the successive steps in the process of winning the ore, and shall finally devote a few paragraphs to parallel changes in such auxiliary functions as drainage and ventilation.

Breaking the Mineral

Two distinct operations are usually required to break metallic ore: the drilling of holes for the insertion of explosives and the detonation of the explosives. In bituminous coal mining, additionally, the seam is undercut; this is to make the coal break into large pieces when the shot is fired, and cause it to fall forward so that it may conveniently be loaded. In the breaking down of bituminous coal seams, cutting occupies a position that corresponds in importance with drilling in metal mining. Actually, drilling is of secondary significance for such soft materials as are encountered in coal mines;[5] cutting, on the other hand, occurs only in the mining of coal.

By 1899, the year when our statistical series begin, mechanized drilling had already been introduced in metal mining. The first mechanical drill, a cumbersome device powered by steam, had been utilized some thirty odd years before to drive the Hoosac railroad tunnel in Massachusetts. A similar drill was adopted by Colorado metal miners before the completion of the tunnel (1875) and it had found its way into Lake Superior copper mining by 1876.[6]

These early drills were of the so-called piston variety. The drill steel was attached to a piston actuated back and forth within a cylinder, and compressed air was the usual source of power. The drill steel was not only driven back and forth, but was also rotated in the process. Before the device was perfected drilling was, of necessity, a difficult hand operation. Hand drilling required individuals of great brawn and considerable skill. In copper, at any rate, it was regarded as "an art that took years to learn."[7] It is not surprising, therefore, that the machine drill began to replace hand methods in copper quite early. In iron mining, on the other hand, machine drilling of soft ores was postponed until

[5] Willard E. Hotchkiss and others, *Bituminous-Coal Mining* (National Research Project, Philadelphia, 1939), p. 20.

[6] Y. S. Leong and others, *Copper Mining* (National Research Project, Philadelphia, 1940), p. 106.

[7] *Ibid.*, p. 110.

well into the twentieth century, although hard ores were machine drilled as early as the 1880's.[8] How far mechanical drilling had spread in the metal mining industries at the turn of the century it is difficult to say, although the frequent mention of mechanical drills in such a contemporary account as the 1902 Census report suggests that their use was not uncommon, especially for copper, gold and silver.[9] In that volume data relating to mines producing those three metals indicate that almost 75 percent of the total quantity of gold and silver ore mined underground and more than 85 percent of the copper ore came from mines using power drills.[10]

The cutting of coal was characterized by advances similar to those in drilling. For the greater part of the nineteenth century coal cutting had been a hand task. Since the cut was usually made under the coal seam, the miner was forced to lie on his side while performing the operation. In this position, working with a pick, he formed beneath the coal seam a wedge-shaped opening which extended for two or three feet and tapered from a foot or more at the front to several inches at the back. It may well be imagined that the undercutting of coal was one of the most back-breaking and time-consuming tasks the underground coal miner had to perform. Not until the cutting machine replaced the miner's pick—a development which dates from about 1880 when mechanical cutters were introduced—was this operation made less onerous.[11] As we might expect, the first cutting machines simulated the hand pick operations and relied on percussive action. This type of machine was the dominant mechanized cutter for the remainder of the century; in 1899 it accounted for 22.7 percent of the underground tonnage.[12] Since then it has been superseded by various types of continuous chain instruments.

[8] Yaworski and others, *Iron Mining,* p. 140.

[9] U. S. Bureau of the Census, *Special Reports,* "Mines and Quarries, 1902," *passim.*

[10] *Ibid.,* pp. 529-30, 476-78. The data on copper do not include Michigan, which reported more than two thirds of all the horsepower used in copper mining and accounted for 53.0 percent of the tonnage mined. It seems altogether likely that the inclusion of Michigan would have resulted in a still higher percentage.

[11] This development was confined to the bituminous fields. See *Report of the Industrial Commission,* Vol. XII (Washington, 1901), pp. 54, 150, 177, 651. To this day anthracite is still cut by hand.

[12] This paragraph and other references to machine cutting are based largely on Hotchkiss and others, *Bituminous-Coal Mining,* Vol. I, pp. 13-19. For data on the percentage of total bituminous coal production cut by machine, see below, Chapter 8, Table 15.

Improvements in breaking metallic ores in recent decades have followed two directions: first, faster and more efficient drilling, and second, greater reliance upon the force of gravity. The latter is epitomized in such a practice as block caving, but it has many less dramatic applications as well. Let us first consider advances in mechanized drilling.

The switch from the piston-type to the hammer-type drill early in this century marks the chief advance in drill models. In the hammer-type drill the piston is not attached to the drill steel, but instead delivers a rapid succession of light blows, with the bit remaining permanently in the hole. This type of drill was found to possess many advantages over the older piston type. It was able to drill "up" holes, which had been very difficult with the piston drill. In addition, different models of the drill could be constructed to suit varying conditions encountered in specific operations. Finally, hollow drill steel, through which a mixture of air and water could be forced in order to keep the hole clean, could now be utilized.[13]

The hammer drill was developed in the 1890's and introduced into copper mining about 1909. Since then it has gained ascendancy in metal mining generally, and the older types of hand and piston drills are by now obsolete.[14] With the years its design has been improved, new drill steels have been developed and the mobility and speed of the drill have been increased. A recent modification has been the use of detachable steel bits. Now the miner can be supplied with enough detachable bits for a day's work, so that sharpened drills need no longer be distributed.[15]

For the most part, modern drills are still powered by compressed air. Many attempts have been made to replace air by electricity,[16] but they have usually been unsuccessful because of the difficulty of converting the rotary motion of the electric motor to the reciprocating action essential in drilling any hard material.[17] Only where auger drills are used, as in the working of such

[13] Leong and others, *Copper Mining*, p. 109. See also C. W. Nicolson, "Compressed Air Drilling" in *Engineering and Mining Journal*, August 1941, p. 104. The reciprocating drill scoured the hole by its own movement, but water was found still more efficient for this purpose.

[14] Leong and others, *Copper Mining*, p. 109; Yaworski and others, *Iron Mining*, p. 140.

[15] Leong and others, *Copper Mining*, p. 112.

[16] Nicolson, *op. cit.*, p. 104.

[17] C. E. Nighman and O. E. Kiessling, *Rock Drilling* (National Research Project, Philadelphia, 1940), p. 38.

relatively soft materials as coal and limestone, has the electric motor been widely utilized. In these drills the spiral drill steel is attached to a rotating rod which can be actuated by an electric motor.[18] It should be noted in connection with auger drilling in coal that its expanded use in the period since about 1925 is directly attributable to the extension of mechanical loading, which made necessary a balanced cycle of mining operations.[19]

Drilling advances alone cannot be credited with the entire improvement in breaking performance in underground mines. Breaking efficiency is strongly influenced also by the nature of the blasting agents utilized, and the period ushered in by the advent of mechanical drilling has, naturally enough, been marked by progress in the manufacture and use of explosives.[20] The introduction of dynamite in copper mining occurred at almost the same time as the adoption of mechanical drilling.[21] As the use of the mechanical drill spread in metal mining, dynamite tended to replace such explosives as black powder and nitroglycerine which were less efficient and more hazardous to use.[22] In coal mining, on the other hand, the continued resort to hand drilling until well into the present century was matched by the retention of black powder for blasting; prior to 1909 black blasting powder was virtually the only explosive for blasting coal.[23] As in drilling, the advances of the present century in blasting have consisted mainly of a large number of small changes that have resulted in a variety of explosives which yield any desired type of fragmentation and are readily adapted to specific conditions.[24] However, progress in drilling and blasting constitutes only one way of improving the efficiency of breaking, and the least dramatic. Let us turn, therefore, to consider the mining methods that dispense with drilling and blasting almost entirely.

In the preceding chapter we referred briefly to caving methods

[18] *Ibid.*, p. 35. Electric drills were already known in coal mining in 1899 (*Report of the Industrial Commission,* Vol. XII, pp. 55, 177).

[19] Hotchkiss and others, *Bituminous-Coal Mining,* p. 20.

[20] Under some conditions liquid carbon dioxide or compressed air may be used to bring down the coal, but for the most part explosives are still employed: *ibid.,* p. 24.

[21] Leong and others, *Copper Mining,* pp. 112-13.

[22] Collins, in Kaempffert, *op. cit.,* pp. 70-71.

[23] Toenges, *op. cit.,* p. 8. Dynamite is not suitable for blasting coal, having too violent a shattering effect; other blasting agents had yet to be developed.

[24] Leong and others, *Copper Mining,* pp. 112-13.

in underground metal mining.[25] It will be recalled that in block caving a thick block of ore is undercut and allowed to break through force of gravity. Besides block caving in its pure form, numerous related devices have been introduced, notably sublevel caving.[26] The latter also employs gravity to break the ore, and is used quite extensively in iron mining. Such caving methods have been fairly widely adopted in copper and iron mining, and to this extent the labor formerly involved in drilling and blasting has for the most part been rendered unnecessary. During the period 1929–37, 16 percent of underground iron ore was produced by sublevel caving,[27] and in 1936 block caving accounted for 18.9 percent of underground copper.[28] The use of improved drilling and blasting techniques with or without caving methods has resulted, in copper mining, in a reduction of the working force engaged in breaking ore from two thirds of the total underground labor, when hand drilling was used, to 20 to 30 percent of the underground labor today.[29]

In the case of bituminous coal, improvements in cutting machines have kept pace with changes in drilling and blasting. As with drills, the most important change in coal-cutting machinery occurred early in the century. The percussive puncher machine, which was the dominant mechanical cutter at the end of the nineteenth century, soon began to be displaced by a fundamentally different type of machine. The new device, known as the chain-breast machine, had a cutting element consisting of "a heavy plate about 44 inches wide, known as the cutter bar, which projects about 6 feet in front of the machine. Around the outer edge of the plate is an endless chain fitted with removable steel bits. When the machine is started the endless chain revolves, and

25 See Chapter 5 above, pp. 111-14; especially Chart 35.

26 See Chart 34 above. Sublevel caving is especially applicable in soft ore bodies which would cave prematurely over wider openings (C. F. Jackson and J. H. Hedges, "Metal Mining Practice," *Bulletin 419*, U. S. Bureau of Mines, 1939, pp. 238-42).

27 Yaworski and others, *Iron Mining*, Table A-22, p. 240. In addition 9.4 percent of underground iron was produced by a combination of sublevel caving and other stoping methods.

28 Leong and others, *Copper Mining*, Table A-13, p. 256. The percentage is based on the recoverable copper content of ore mined, not the tonnage of ore. The latter basis would yield a far higher percentage (42.0 percent to be exact) but is a less significant measure because of the lower tenor of caved ore. Data relating to the efficiency and relative importance of different methods of mining copper will be found in Chapter 12 below, Tables 23 and 24.

29 *Ibid.*, p. 106.

the cutter bar is automatically fed forward against the coal." [30]

The changes instituted since the introduction of the chain-breast machine have not modified the fundamental design of the cutter mechanism, although they have enhanced the efficiency and ease with which the machine may be worked and moved about the mine. With the early machine, the full width of the working face could not be cut unless the machine were withdrawn after each cut and moved across the face to make another cut, and so on until the entire face had been covered. One of the first modifications permitted continuous operation for the full width of the working face. The short-wall machine, which embodied this feature, came into general use about 1910 and rapidly replaced the earlier types. Shortly thereafter, another important change enabled the machine to cut at any elevation in the coal face without being removed from the truck on which it was transported.

The major modifications in the machine were devised before the first World War. Since that time numerous further improvements have rendered the machine cutter more efficient. Among these may be listed such items as increase in the size of the cutter bar, improvement in cutter bits and increases in power. In 1938 the mechanical cutter was responsible for 87.5 percent [31] of total bituminous coal production, but it is still rarely employed in anthracite mines, where the nature of the deposits has obstructed mechanization in cutting.[32]

Loading the Mineral

The loading of broken mineral is an operation that occurs midway between breaking and hauling. Although loading thus occupies a central position in the mining process, it remained a hand job in many mining industries long after breaking and hauling had been mechanized. Indeed the development of mechanized equipment to replace hand loading is strictly a post-World War phenomenon, in spite of the fact that hand loading was the most laborious of the underground miner's operations in the coal and iron ore industries.[33] It is not surprising, then, that during the

30 Hotchkiss and others, *Bituminous-Coal Mining,* p. 15.

31 See below, Chapter 8, for data on machine cutting of bituminous coal.

32 Harry Jerome, *Mechanization in Industry* (National Bureau of Economic Research, 1934), p. 133.

33 Yaworski and others, *Iron Mining,* p. 151; Hotchkiss and others, *Bituminous-Coal Mining,* p. 114.

period of its developing use mechanical loading has played an extremely important part in increasing efficiency in underground mining as a whole. In loading, more than in any other single function, mechanization fosters an increased tempo of mine operations in general. It may indeed be said that the balanced cycle of underground operations is a concomitant of the post-World War mechanization of the loading process.[34]

Of course, technological advance in loading did not begin with the introduction of mechanical loaders. Before this innovation the efforts of those who sought to make the operation more efficient were directed toward improving the means and methods of hand shoveling. Among other things, shovels were redesigned, lower mine cars were built, and miners were instructed in proper techniques of shoveling. Even these small changes made for sizable increases in labor efficiency.[35] In addition, the utilization of gravity methods of loading in many cases predated the mechanical loader. As in the case of breaking, the adoption of techniques which took advantage of the force of gravity succeeded in eliminating much hand labor formerly necessary. But gravity breaking and gravity loading did not necessarily go together. Thus in iron mining, where sublevel caving is widely used, gravity methods of loading are rather definitely confined to a few deposits. Here, therefore, mechanical loading was a great boon to mine efficiency.[36] On the other hand, gravity loading is used in copper even in some mines—for example in shrinkage stoping—where block caving is not practiced.[37]

More, perhaps, than any other device, the mechanical loader must be closely adapted to the peculiar physical circumstances of the individual mine.[38] In consequence loading equipment appears in a quite extraordinary range of design and type. This fact makes it impossible for us to discuss the mechanization of the loading

[34] Hotchkiss and others, *Bituminous-Coal Mining*, pp. 140-42.

[35] Leong and others, *Copper Mining*, p. 114.

[36] Yaworski and others, *Iron Mining*, p. 151.

[37] L. N. Plein, F. E. Berquist and F. G. Tryon, *Mechanization Trends in Metal and Nonmetal Mining as Indicated by Sales of Underground Loading Equipment* (National Research Project, Philadelphia, 1937), p. 3.

[38] "There is no universal loader and there never will be, because of the wide variations in underground conditions and requirements." Charles E. Van Barneveld, *Mechanical Underground Loading in Metal Mines* (University of Missouri: School of Mines and Metallurgy, Bulletin, Technical Series, Vol. VII, No. 3, Rolla, Mo., 1924, p. 75).

process with the thoroughness it deserves. We shall describe only a few leading types of loader in the more important industries.

The first World War may serve as a starting point for a discussion of the mechanization of underground loading, no matter what mining industry we consider. Although attempts at mechanization had been made before then, the real impetus was undoubtedly provided by the labor shortage during the first World War and early post-war period.[39] At that time two types of mechanical loaders were introduced into metal mining: the shovel loader and the scraper.

The shovel loader at first seemed the preferable device and was, therefore, adopted in many metal mines. This machine, which can best be described as a miniature power shovel, involved serious mechanical difficulties and was, in addition, essentially ill adapted to small, artificially supported workings such as are encountered in underground iron ore and nongravity copper mines.[40] Hence in copper and iron mining mechanical shovel loaders met with little success and were rapidly superseded by scraper mechanisms. The shovel loaders continued, however, to be utilized in development work where they are not handicapped by insufficient head room, and they have greatly increased the efficiency of drifting or tunneling.[41] It should be noted also that shovel loaders have been used with great success in the Southeast Missouri lead field, where underground workings are sufficiently roomy to accommodate the machines.[42] In recent years the introduction of a smaller power shovel has made for a renewed use of this machine in underground iron and nonferrous mining, but still largely for development work.[43]

A more successful loading device for use in underground metal mines is the scraper. Even in the Southeast Missouri lead district, where 100 percent mechanization of loading has been achieved in recent years, scrapers have to some extent replaced shovel load-

[39] Hotchkiss and others, *Bituminous-Coal Mining*, pp. 114-15; Yaworski and others, *Iron Mining*, p. 152; C. F. Jackson, in the Foreword to "Mechanical Shoveling in Underground Metal Mines," by McHenry Mosier and J. H. Steinmesch, *Bulletin 423* (U. S. Bureau of Mines, 1940).

[40] Yaworski and others, *Iron Mining*, p. 152; Leong and others, *Copper Mining*, p. 117.

[41] Leong and others, *Copper Mining*, p. 117.

[42] Andrew V. Corry and O. E. Kiessling, *Grade of Ore* (National Research Project, Philadelphia, 1938), p. 80.

[43] Plein, Berquist and Tryon, *op. cit.*, p. 12.

ers.[44] The scraper consists of little more than a scoop, pulled by a rope attached to a hoist, in which the ore is dragged along the floor. It is superior to the shovel loader in that it requires very little head room and can also be used for hauling. Actually the device does not load, but rather serves to drag the material to a convenient elevated point from which it can be discharged into a mine car or an ore chute. Initially, if we may generalize on the basis of iron mining experience, the scraper was operated by the timber hoists which were already available. But this provided only a mechanical means of dragging the scraper toward the hoist, with the return trip powered by hand. By 1923, however, double-drum hoists driven by compressed air were being introduced.[45] More recently, the increase in the capacity of hoisting equipment has favored the substitution of electric power.[46]

Up to this point we have discussed the loaders that eliminate hand shoveling entirely; these, as is clear from the references to their use, are found mainly in metal mining. In coal mining similar machines are coming into use, but before we treat the fully mechanized loading of coal it is well to consider another type of machine which merely reduces the labor involved in hand shoveling without eliminating the operation entirely. Such machines have been widely employed in coal mining in the past.

The most important device to reduce hand shoveling is the pit-car loader, essentially an elevating conveyor. With this type of machine the miner need lift the coal only a short distance from the floor of the mine onto the lower end of the conveyor, which in turn lifts the coal into the car. Thus the necessity for lifting the coal the entire height of the car is obviated, and much labor is thereby saved. This device was introduced in bituminous coal mines at about the same time that the shovel loader found its way into metal mining; it was taken up by the coal operators mainly because it did not require important changes in existing mine practice. Although it was of low capacity, it permitted hand separation of impurities and could, therefore, be readily fitted into the existing mine routine.[47]

[44] Corry and Kiessling, *Grade of Ore,* p. 80.

[45] Yaworski and others, *Iron Mining,* pp. 152-53.

[46] McHenry Mosier, "Underground Loading," *Engineering and Mining Journal,* August 1941, p. 107. The increase in the size of equipment may be appraised from the fact that in 1923 hoists of from 4 to 7½ horsepower were used, whereas today they range up to 150 horsepower (Plein, Berquist and Tryon, *op. cit.,* p. 9).

[47] Hotchkiss and others, *Bituminous-Coal Mining,* p. 120.

The pit-car loader, which represents an intermediate stage between hand and fully mechanized loading, is still used in many mines.[48] Recently, however, there has been a tendency to replace it with the completely mechanical mobile loader. This loader is based either on the shovel principle or on the gathering principle.[49] The shovel type is similar to the machine already discussed in connection with metal mining. The gathering type uses claw-like arms which push the coal onto a conveyor.

Scraper mechanisms have not been widely used in coal mining mainly because resource conditions do not favor them. However, the combination of loading with hauling which the scraper offers in metal mines is found in coal in the hand loaded conveyor. This consists of an ordinary conveyor unit, which, in recent years, has been adapted to all systems of coal mining.[50] The conveyor is brought up to the working face and the coal is loaded onto it, to be carried either to mine cars or to a mainline conveyor system. This appears to be more of a haulage than a loading mechanism, yet it is of some importance in loading since it reduces the height to which the coal must be lifted by the miner and eliminates the need for bringing mine cars into the rooms where the mining is carried on.

Since mechanical loading is of comparatively recent origin, it is interesting to see how far its use has spread. The extent to which the various mechanical loaders have been adopted is more easily determined in coal mining than in other mining industries. Available data indicate that about 30 percent of the underground tonnage of bituminous and anthracite coal is mechanically loaded.[51] For other mining industries statistics on mechanized loading are lacking, but there are scattered facts which roughly indicate its extent. In iron mining, for instance, scraper mechanisms are known to be widely used in the Lake Superior region, the most important underground producing center. In copper mining, too, scraping has been widely applied in Michigan, where resource conditions are favorable.[52] For copper mining in general, however, the field for mechanized loading is definitely limited

[48] Toenges, *op. cit.*, p. 11.

[49] Hotchkiss and others, *Bituminous-Coal Mining*, p. 120.

[50] *Ibid.*, p. 125-30.

[51] For data on the mechanical loading of coal, see below, Chapter 8, Table 15, and Chapter 9, Table 17.

[52] Plein, Berquist and Tryon, *op. cit.*, p. 9.

because of the wide use in this industry of gravity methods of loading which render mechanical devices unnecessary, or of the square-set technique of mining [53] which involves timbering that is too close to permit mechanized loading.[54] As for lead and zinc mining, we have already noted the fact that loading in Southeast Missouri lead mines is 100 percent mechanized. This has contrasted markedly, at least until recently, with the adjacent Tri-State [55] lead and zinc producing district where loading has been done almost entirely by hand.[56]

With regard to the other metals, all that can be said is that mechanical loading is used in mining them all, though little is definitely known as to the amount of production for which such loading accounts. The indications are that the metals, as a group, do not yet use mechanical loading to as great a degree as do the nonmetals, especially coal. To be sure, mechanical devices are less necessary in loading metallic ores than in loading coal, owing to the greater scope for gravity methods in the former case.

There can be little doubt that the mechanization of loading has been of great importance in increasing productivity in underground mining in recent years. In many mines, loading was the last function to be mechanized, so that its adoption completed the chain of mechanized processes, with a resultant gain in over-all efficiency. In other mines—particularly coal—mechanization of loading replaced a hand process which had consumed the greatest portion of the underground mining crew's efforts. In addition, the use of mechanical loading called forth the mechanization of other functions to preserve the balance between different parts of the cycle of mining operations. In this sense its indirect effect on the productivity of underground mining has been potent indeed.[57]

[53] See above, Chapter 5, pp. 101-02.

[54] Plein, Berquist and Tryon, *op. cit.*, p. 3.

[55] The Tri-State area includes parts of Kansas, Missouri and Oklahoma.

[56] "These two districts, lying side by side, illustrate how largely the factors of size of operation and character of deposit affect the utilization of machinery. In the Tri-State area, the less regular character of the mineralization and of the underground workings, the smaller holdings, the prevalence of the leasing system, the use of small 'cans' instead of large-capacity cars in haulage, and other factors have worked to favor hand loading" (*ibid.*, p. 17). This quotation was written in 1937; we understand that since 1938 mechanical loading has developed rapidly in the Tri-State area, as it had already done in Southeast Missouri.

[57] For instance, we read that "by speeding up the mining process, scraper loading has permitted the concentration of work into fewer places, thereby reducing the amount of maintenance work and allowing more efficient utilization of transporta-

Transporting the Mineral

In most underground mines the transportation of minerals (as well as of men and supplies) involves two distinct operations: (1) horizontal movement from the working face to the mine shaft, or hauling; and (2) vertical movement from the underground level to the surface, or hoisting. Trends in the first of these operations include changes from hand to animal to mechanical haulage; and advances, not only in rail equipment, but also in the utilization of scrapers and conveyor systems (discussed above). As for hoisting, the second of these operations, we have already noted that along with pumping and ventilation, this function had to be mechanized in order that mining might be carried to greater depths in the late nineteenth century.

For the most part underground haulage systems were not mechanized until after the opening of the present century. Even though electric locomotives had been introduced into coal mines in 1887 [58] and into metal mines in the 1890's,[59] hand and animal traction were still chiefly employed in 1899.

In some cases, as in coal, such primitive methods were supplemented by rope or chain haulage on the mainline, but this was not a marked improvement, since the speed of rope haulage was usually no greater than that of the mule.[60] Of course both animal draft and rope haulage marked an advance over the use, at a still earlier date, of hand tramming underground, but even such modest improvements were not universally applied. They were widely adopted in coal mining, but for iron ore hand methods held sway until they were replaced by mechanical traction in the twentieth century.[61]

Hoisting, as we might expect, was more generally mechanized than haulage in the late nineteenth century. To the extent that

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tion and other facilities. The two- or threefold increase in output per miner in the stopes has made it possible to maintain a specified production with one-half to one-third the number of stopes. This has permitted closer supervision of workings, easier distribution of supplies, simpler ventilation, easier drainage, and other economies" (Yaworski and others, *Iron Mining,* p. 158). This chain of developments has also occurred in coal mining.

[58] Van Barneveld, *op. cit.,* p. 40.

[59] Yaworski and others, *Iron Mining,* p. 144; Leong and others, *Copper Mining,* p. 122.

[60] Hotchkiss and others, *Bituminous-Coal Mining,* p. 25.

[61] Yaworski and others, *Iron Mining,* p. 144.

mineral production came from deep mines requiring vertical shafts, powerful hoisting units were essential. This was especially true of mines producing copper, gold and silver. Thus in the 1902 Census we find evidence of extensive use of hoists, usually powered by steam, in these industries.[62] As for coal, operations were usually not very deep, so that hoisting in general was less important here than in metal mining.

Electric locomotives, first introduced into mining operations toward the end of the nineteenth century, came into widespread use during the first decade and a half of the present century. Frequently they superseded mules directly, without the intervention of rope haulage. Their application, however, was confined almost entirely to mainline haulage. In newly-made drifts, mine rooms, and other small workings, hand and animal tramming remained predominant.[63] Such workings cannot easily accommodate overhead trolley wires; moreover the point where loading occurs is continually advancing. The difficulty was partially overcome by the cable-reel type of gathering locomotive.

A more recent development has been the introduction into underground mines of storage battery locomotives—self-contained units carrying their own source of power. This machine dispenses with wiring and is therefore well suited to the task of gathering haulage, i.e., transferring mine cars from small workings to the mainline. Reliable battery locomotives were apparently introduced into mining about the time of the first World War, and since then their use has expanded rapidly, so that today both mainline haulage and gathering are largely mechanized.[64] It should be noted, however, that in metal mining the most rapid extension of mechanized gathering haulage did not follow immediately upon the advent of the battery locomotive, but rather awaited the introduction of the small and compact 1½ ton battery locomotive in the early 1920's.[65]

Today both trolley and storage battery locomotives are used; the choice of one or the other depends upon the nature of the mine workings and the material being handled. However, because

[62] "Mines and Quarries, 1902," pp. 476-78, 526-30.

[63] Hotchkiss and others, *Bituminous-Coal Mining,* p. 26; Leong and others, *Copper Mining,* p. 123.

[64] F. G. Tryon and others, "The Mineral Industries" in *Technological Trends and National Policy* (National Resources Committee, 1937), p. 152; Leong and others, *Copper Mining,* p. 125.

[65] *Ibid.,* p. 125; Yaworski and others, *Iron Mining,* p. 146.

of the existence of both types, haulage can be mechanized in practically all workings. Hand and animal haulage still prevail in many small mines.[66] An important illustration of such continued use of hand and animal methods is found in the Tri-State lead and zinc district, where mechanical hauling is still rare.[67]

Throughout the period, of course, there has been continuous improvement in the construction of mine locomotives. In general, weight and power have been increased, with the ratio of horsepower to weight constantly rising through a transfer of weight from the frame to the motor.[68] There have also been marked changes in the design of mine cars. These have resulted in larger cars with less deadweight (because of the use of alloy steels in construction) and in constantly improved dumping mechanims. The most important among the latter group of changes has been the switch from the end-dump car of hand-tramming days to the bottom-dump and side-dump cars of today, which do not have to be uncoupled for dumping.[69]

We have already discussed scrapers and conveyor systems in connection with the mechanization of loading. For hauling, scrapers are widely used in metal mines, but only for transportation over limited distances. Conveyor systems, on the other hand, are adapted to relatively lengthy hauls, and in coal mines have recently been used with mobile loaders.[70] In the last few years conveyor systems have been installed in some iron mines, but their application in metal mining is still unimportant.[71]

It is to be expected that improvements in the underground haulage system have been matched by advances in hoisting. In the 1902 Census we find the following observation: "In a district where it is cheaper to sink a new shaft than to tram ore 600 or 700 feet underground, central shafts of large capacity are out of place." [72] Today a single, large, multiple-compartment shaft may serve a huge underground copper mine; here is clear evidence that improved underground haulage has exerted an influence on

[66] Jackson and Hedges, "Metal Mining Practice," pp. 169-72.

[67] "The Story of the Tri-State Zinc and Lead Mining District" (convention souvenir, American Institute of Mining and Metallurgical Engineers, Joplin, Mo., 1931), p. 21.

[68] Yaworski and others, *Iron Mining*, p. 145.

[69] *Ibid.*, p. 146.

[70] Hotchkiss and others, *Bituminous-Coal Mining*, p. 28.

[71] Jackson and Hedges, "Metal Mining Practice," pp. 173, 188-90.

[72] "Mines and Quarries, 1902," p. 462.

hoisting technique. Not only must improved haulage have made it cheaper to tram than to sink additional shafts, but it must also have induced more efficient hoisting to match the accelerated pace of underground transportation systems.

The change from small shafts to the larger shafts of today could not, of course, have been accomplished without continuous improvement in hoisting equipment. One of the most important of these advances has been the development of the system of hoisting in balance. Such a system utilizes a double drum which enables one cable to be wound and the other unwound simultaneously: one cage or skip is raised while another is lowered. This method was developed around 1900 and since then most installations in mining seem to have utilized balanced hoisting.[73]

Another significant change has been the increasing use of skips (or containers) rather than cages for hoisting.[74] Skips have been in use since about the turn of the century. Incidentally, the development of a satisfactory, self-dumping skip made possible the substitution of vertical for inclined shafts in the Lake Superior iron region.[75] Today hoisting by skip has largely replaced hoisting by cage in metal mining. Under certain circumstances, however, the use of cages may still be preferable.[76] Indeed, even such an old-fashioned device as the bucket—which gave way to the cage in the nineteenth century [77]—is still used in the Tri-State lead and zinc district, where relatively large tonnages are handled.[78]

Advances in hoisting have paralleled changes in other mechanized mine equipment. Speed and capacity have risen: in this advance the utilization of electric power has played a large part. Also, materials used in the construction of skips have been im-

[73] Yaworski and others, *Iron Mining*, p. 142; Leong and others, *Copper Mining*, p. 135.

[74] "Use of the cage involves loss of time both in loading the cars onto the cage and in removing them at the surface, requires labor to perform the loading and unloading, ties up mine cars in the process, and necessitates hoisting deadweight of the cars," while "adoption of the skip and skip pocket has brought about a considerable saving in labor and time. It has greatly reduced the labor previously engaged in loading and unloading, eliminated a considerable portion of the delay and congestion both at the shaft and the haulageways, and increased the capacity of the hoist by 25 to 40 percent by obviating the necessity of raising and lowering the deadweight of the mine cars." Leong and others, *Copper Mining*, pp. 135-36.

[75] Yaworski and others, *Iron Mining*, p. 141.

[76] Jackson and Hedges, *op. cit.*, p. 205.

[77] 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), p. 125.

[78] Jackson and Hedges, *op. cit.*, p. 203.

proved with a consequent reduction in deadweight. These and other such changes have operated to make possible concentration of hoisting in large single shafts in response to the pressure exercised by the faster tempo of underground mining operations. Indeed, the point has been reached where the efficiency of hoisting is no longer considered a limiting factor even when mining at much greater depths is contemplated. As Read points out,[79] ore can be successfully hoisted, without undue expense, from depths two or three times as great as the average for mines in the United States today.

Auxiliary Functions

Technological change in underground mining has not been confined to advances in the primary functions of breaking, loading and transportation. Advances have been registered also in methods of mine drainage, ventilation, lighting, support and other so-called auxiliary functions. Improvements in these fields have rendered possible the working of seams or veins which in former times could not have been exploited. They must also have affected productivity levels, but mainly in ways which are indirect and difficult to evaluate. For this reason, and because drainage and ventilation, in particular, are highly specialized functions, an adequate treatment of them would of necessity be both prolix and technical. We shall confine ourselves, therefore, to a few general remarks.

The indirect operation of such improvements is well illustrated by changes in mine ventilation. For the greater part of the nineteenth century artificial ventilation was not used underground except in coal mines. Even here the natural draft was often considered sufficient, perhaps with the assistance of mechanical fans on the surface or of a pipe leading to a furnace in which the suction of the heated air drew the foul air from the mine.[80] Such devices were usually lacking in metal mines because of the belief among many mining men that only in coal mining was circulation of air at the working face necessary.[81] However, as metal mining was carried to greater depths, and as the working face receded farther from the shaft, mechanical ven-

[79] *Technological Trends and National Policy*, p. 164.
[80] Julihn, *op. cit.*, p. 125; Leong and others, *Copper Mining*, p. 151.
[81] *Ibid.*, p. 153.

tilation came to be recognized as a necessary condition for the continuation of operations. A description of the early days of the Comstock lode reveals how the lack of devices able to counteract the heat operated to reduce miners' efficiency to a very low level. Temperature in drifts sometimes went up to as high as 130°F., and although air pipes driven by powerful engines were placed close behind the men laboring at the face they could not work for more than a very few minutes in each hour, and were constantly driven to bathe their heads in streams of water.[82] This is, no doubt, an extreme example, but it serves to illustrate the deleterious effect of inadequate ventilating devices on labor efficiency.

Inventions of the twentieth century have succeeded in insuring adequate ventilation for underground mines. Improvements have been stimulated by increased knowledge of the relationship between labor efficiency and the temperature, humidity and cleanliness of the air. Physiology and engineering have in fact joined hands. The effect of such developments does not lend itself to measurement, but there can be no doubt that it must have been considerable.

So, too, improved systems of drainage must have exercised their effect on underground efficiency. With greater depth in mining the task which pumping machinery must perform becomes more considerable, if only because of the greater height to which water must be raised. Here again the difficulties created by water in underground workings must be overcome if miners are to be able to work efficiently.

Unlike ventilation and drainage, the task of illumination has not been burdened with increasing natural difficulties; hence any advance in the effectiveness with which it is provided constitutes a clear gain. That it has been more effectively provided is due mainly to the increasing use of electric lighting in underground mining. This has been a tremendous boon, particularly in coal mines. Prior to the use of electricity, portable devices which would give sufficient light and also provide the fullest safety against fire damp were not to be found.[83]

Finally we may consider the function of mine supports. The

[82] Robert M. LaFollette (ed.), *The Making of America*, Vol. 6 (Morris, Chicago, 1906), pp. 25-26.

[83] E. N. Zern, *The History of Mine Lighting*, College of Engineering, West Virginia University, Series 2, No. 1 (Morgantown, W. Va., 1916), p. 27.

effect of modifications in methods of support resembles that of changes in the primary mine functions, in that increased efficiency of support results in a reduction in the amount of time the miner must devote to this task, and enables him to spend more time in the primary functions associated with winning the mineral. The amount of the underground miner's time and effort that goes into timbering for support has been cut down in two ways. First, changes in mining methods have operated to reduce timbering for support to very minor proportions. Thus, the use of shrinkage stoping and caving methods [84] in modern iron and copper mining, in place of square-set timbering, has resulted in a great reduction in the number of artificial supports required, and hence the labor involved in their maintenance. By and large, however, support is still necessary, and the second type of improvement comprises means of reducing the time required in erecting and maintaining such supports. Among the most important of these are: (1) the use of preservatives which prolong the life of the timber, and (2) the standardization of timber sets, with a consequent transfer of preparation from the mine to a surface carpentry shop which may utilize machinery.[85]

OPEN CUT MINING

As we have seen, the exploitation of this nation's mineral deposits has for the most part required underground operations. Yet where conditions are suitable, and the deposits do not occur too far below the surface, open pit methods of winning the mineral have proved very efficient. This is true especially of the quarrying of stone; but it applies also in many instances to the extraction of coal, copper, iron ore and other minerals. In both coal and metal mining, surface operations have increased in relative importance in recent decades, while the technology of open pit mining itself has made striking advances.[86]

[84] See above, pp. 110-14.

[85] Leong and others, *Copper Mining*, p. 150.

[86] Surface mining is probably the oldest form of mineral extraction since surface outcroppings of minerals were probably first to be exploited. In the United States, for instance, many early operations are known to have been of the surface variety, but these amounted to nothing more than gathering loose outcrops or digging with crude hand devices. This type of mining was superseded by underground workings when depth became too great for hand digging. In the present context we are interested not in these crude beginnings but rather in the present-day large-scale surface exploitation of iron, copper, and bituminous coal made possible by the devel-

In open cut mining the difficulties and hazards of underground mining are obviated. In this connection it is sufficient to note that such tasks as shaft sinking, tunneling, and timbering for support, all of which absorb a considerable amount of labor, are unnecessary in surface mining. Nor is it necessary to provide artificial lighting and ventilation, both of which are required in underground workings. Against these advantages must be set the disadvantage that considerable quantities of waste material, known as "overburden," have generally to be removed before the mineral can be reached. Consequently, the advantages of surface mining could not be realized to any great extent until equipment became available for moving material, chiefly in a horizontal direction, on a rather large scale. The development of such equipment—the mechanized means of breaking, loading and hauling ore and overburden—are considered in the remainder of this section. The history of open cut mining is largely the history of the power shovel.

In 1892, when operations began on the Mesabi iron ore range in Minnesota, the power shovel was already available in elementary form. Before this time it had been used for making railway cuts and for general excavation, and had even been employed, although not to any great extent, in stripping overburden in coal mining and in loading the mined product. Indeed, as early as 1877 a power shovel had been used in a coal strip pit; but this early machine had to be moved by block and tackle and could be propelled only in one direction.[87] It was not until 1890 that a shovel embodying backward and forward self-propulsion was introduced in strip mining.[88] This type of shovel, which was utilized in the first workings on the Mesabi range, was powered by steam and traveled on rails (the so-called railroad type steam shovel).[89]

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opment of the power shovel (which may be dated roughly by the opening of the Mesabi iron ore range in 1892). Large-scale surface copper mining did not begin until 1906 and open cut coal operations, although undertaken quite early, were of slight importance until the World War period.

Since changes in crushed stone technology in the present century have paralleled those in open cut metal and coal mining they will be included in this discussion. Other minerals won by surface methods—notably dimension stone, phosphate rock, bauxite, and placer gold—utilize more individualized production techniques, some of which will be treated separately.

[87] F. E. Cash and M. W. von Bernewitz, "Methods, Costs, and Safety in Stripping and Mining Coal, Copper Ore, Iron Ore, Bauxite, and Pebble Phosphate," *Bulletin 298* (U. S. Bureau of Mines, 1929), p. 2.

[88] *Ibid.*, p. 3.

[89] Yaworski and others, *Iron Mining*, p. 89.

It was of relatively small dipper capacity and was able to swing only through a limited arc.[90]

The use of power shovels in loading implies a certain stage of technical evolution in the associated tasks of breaking and hauling the ore, for if these closely related jobs cannot be performed with sufficient speed for the shovel to function more or less continuously, the advantage of power loading is in good part lost. So far as concerns breaking, power machines were available for blast-hole drilling in the 1880's and were being successfully used in open cut iron mining in Pennsylvania, where they had been introduced in 1882.[91] But they made little headway in open cut iron mining elsewhere, and hand methods in fact held sway until well into the second decade of the present century. The superiority of the machine method over hand methods was apparently not very great, at least when relatively soft materials, such as those encountered in the Mesabi range, were worked.[92] The crushed stone industry, too, was dominated by hand drilling techniques during this early period.[93] As for haulage, we find steam locomotives used quite generally in open cut iron mines several years before the opening of the present century.[94] The crushed stone industry, on the other hand, which had not yet adopted the power shovel, was still utilizing in 1900 the primitive haulage methods already discarded in iron mining. Hand and animal haulage were widespread and only in relatively few cases had small steam dinkeys replaced horses in drawing the small wooden cars along narrow gauge tracks.[95]

The development of the power shovel typifies mechanical progress in open cut mining. The railroad-type steam shovel able

[90] Although the power shovel was used in coal and iron mining during the 1890's, it was not adopted in the crushed stone industry until the first decade of the present century. And even at this late date it was used mainly for stripping overburden, while loading remained essentially a hand operation. This lag is explained by the fact that the chief products of crushed stone operations at this time were limestone for flux and lime, both of which required hand sorting. Moreover, many crushed stone enterprises are small and operate only intermittently. Not until expanding industrialism created a demand for crushed stone in construction and road building was the industry able to adopt the power shovel and other mass production devices. See Harry S. Kantor and Geoffrey E. Saeger, *Crushed-Stone Industry* (National Research Project, Philadelphia, 1939), p. 27; also Nighman and Kiessling, *Rock Drilling*, p. 50.

[91] Yaworski and others, *Iron Mining*, p. 80.

[92] *Ibid.*, p. 81.

[93] See below, p. 142.

[94] Yaworski and others, *Iron Mining*, p. 101.

[95] Kantor and Saeger, *Crushed-Stone Industry*, p. 24.

to swing only through a limited arc, which was standard equipment in open cut operations until well into the decade following 1910, has been gradually modified until it has become the full revolving, caterpillar traction, electric shovel of today. The full revolving shovel was introduced during the period 1915–20,[96] although its practicability was not fully realized until the shovel was taken off railroad track.[97] In the early post-war period the shovels were first mounted on caterpillar treads,[98] an advance which one authority writing in 1930 called the "greatest in shovel practice during the past 20 years." [99] At about this time, too, the first electric shovels were introduced at a few operations.[100] The general adoption of each of these innovations has been a long, slow process, and one that is still continuing.[101]

It is obvious that the initial change from hand to machine stripping and loading must have resulted in a large increase in open cut productivity. Even with the first crude power shovels used in iron mining, the working crew of 10 men is estimated to have accomplished 6 to 12 times as much during a work shift as was possible with hand labor methods.[102] Efficiency was further

96 Yaworski and others, *Iron Mining*, p. 92.

97 Kantor and Saeger, *Crushed-Stone Industry*, p. 52.

98 E. D. Gardner, C. H. Johnson and B. S. Butler, "Copper Mining in North America," *Bulletin 405* (U. S. Bureau of Mines, 1938), p. 136. It is interesting to note that the post-war use of caterpillar traction was stimulated by the development of equipment of this kind in World War military operations (A. B. Parsons, *The Porphyry Coppers*, American Institute of Mining and Metallurgical Engineers, 1933, pp. 379-81). It had also been used previously in agriculture.

99 Quotation from A. Soderberg, cited in E. D. Gardner and McHenry Mosier, "Open Cut Metal Mining," *Bulletin 433* (U. S. Bureau of Mines, 1941), p. 8.

100 *Ibid.*, p. 11; see also Leong and others, *Copper Mining*, p. 39.

101 The gradual manner in which improvements in power shovel practice have been adopted is evident even in open cut copper mining, which represents the peak in large scale operations, as can be seen in this quotation from Leong and others, *Copper Mining*, p. 45:

> It should be pointed out, however, that there is always a time lag between the development of a new invention or the improvement of an old one and its general adoption. Thus there are only a few power shovels in service at open-pit copper mines that embody all the advanced features of electric shovels. The huge outlays already made for older types of loading equipment naturally limit the rate at which it appears economical to replace such equipment with more modern machines. In many instances operators have deemed it advisable to improve their existing machines by adopting some of the latest features instead of discarding the old for new equipment. With the advent of caterpillar traction, the old steam railroad-type shovels were modified by placing one tractor under each jack-arm and another in the rear. When the electric shovels proved their superiority over the steam machines, steam engines were replaced by electric motors.

102 Yaworski and others, *Iron Mining*, p. 88.

increased by changes made after 1900. "Whereas the early Mesabi power shovel manned with a crew of from 7 to 12 men loaded 1,000 to 2,000 tons of ore in 10 hours, the largest and most efficient shovels now in use with 2- or 3-man crews can load ore at the rate of 1,000 tons in 1 hour." [103] Changes in loading performance resulting from more recent improvements are cited in the National Research Project's report on *Copper*:

> At the Utah copper mine the railroad-type steam shovels with 3½-yard dippers loaded, on the average, 2,350 tons of ore per 8-hour shovel-shift in 1923, compared with 5,200 tons loaded, on the average, in 1934 by electric shovels mounted on caterpillar crawlers and using 4½-yard dippers. The new full-revolving shovels equipped with 5-yard dippers which this mine has recently acquired have a maximum capacity of 8,000 tons per 8-hour shift and an average capacity well over 6,000 tons. At the Chino mine the cubic yards of material loaded per 8-hour shovel-shift increased gradually from 825 in 1923, when the old-type railroad steam shovels were in use, to 1,280 in 1931, when the loading machines were modernized.[104]

Improved loading performances would not have been possible unless advances in equipment used in related tasks matched the advance of loading machinery. Mechanical drilling, which was rare before the turn of the century, replaced hand drilling on a wide scale. Even in iron mining, the last stronghold of hand drills, power drilling was generally adopted after the first World War.[105] The trend in drilling tools since the start of open cut copper mining has been "toward heavier, more powerful and mobile" models of drills already in existence, and these improvements were "accompanied by gains of 200 to 300% in footage drilled per man-shift." [106] In recent years the substitution of other sources of power for steam—notably compressed air and electricity—the improvement in drilling bits, and the development of the self-propelled machine traveling on caterpillar treads, have contributed to increased efficiency.[107] A striking result of the increased depth to which drilling may economically be carried has been the development of higher benches in open cut metal mining, and

[103] *Ibid.*, pp. 88-89.
[104] Leong and others, *Copper Mining*, p. 47.
[105] Yaworski and others, *Iron Mining*, p. 80.
[106] Nighman and Kiessling, *Rock Drilling*, p. 107.
[107] Gardner and Mosier, *op. cit.*, pp. 7, 108.

the shift from multiple-bench to single-bench operations in crushed stone quarries.[108] This has not only enabled operators to take advantage of larger shovels, but has greatly facilitated the transportation of the mined product.[109]

Improvements in haulage have followed the same general pattern. Here the increase in the size of locomotives and cars and the substitution of standard gauge for narrow gauge are indicative of a general tendency for standard railway practice to replace smaller scale mine railway practice.[110] In a few cases, too, the haulage system has been electrified, but steam is still the predominant source of power.[111] The productivity of open cut operations has also been increased by the substitution of mechanical track shifting for laborious hand methods. At the Utah Copper Company, for example, 5 or 6 times as many workers would be required for track shifting in the absence of the mechanical shifter.[112] A recent change which has been of importance in coal and crushed stone is the introduction of the motor truck.[113] The superiority of the truck derives mainly from its greater mobility and flexibility, which allow it to be placed in a position for loading with the least movement of the shovel.

MECHANIZATION IN STONE QUARRYING

Although limestone and marble are sometimes produced from underground quarries, the stone industries offer an important example of open cut technique. In most respects the production of crushed stone, in particular, resembles other forms of open pit mining. Often the same problems are encountered, and similar equipment is used, as in the mining of coal or iron from surface deposits. Nevertheless, the stone industries possess sufficient peculiarities to justify separate consideration.

[108] Nighman and Kiessling, *Rock Drilling*, pp. 76, 95. A bench is a level of operations. Thus if a layer 100 feet high is removed in two equal stages, we should speak of the use of benches 50 feet high.

[109] Yaworski and others, *Iron Mining*, p. 88.

[110] Gardner and Mosier, *op. cit.*, p. 21.

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

[112] Leong and others, *Copper Mining*, p. 56.

[113] Hotchkiss and others, *Bituminous-Coal Mining*, p. 91; also Kantor and Saeger, *Crushed-Stone Industry*, p. 58.

Trucks have been used in regular haulage at open cut metal mines only in small operations. Elsewhere, their use in metal mining has been confined to clean-up operations in pits that have become so deep that the remaining ore would not justify the cost of extending the track system (Gardner and Mosier, *op. cit.*, pp. 4, 16).

Crushed Stone

The quarrying of stone has a longer continuous history than most other forms of surface exploitation. Consequently, it might be thought that the crushed stone industry should be the original and prototype of all open pit mining, but this is not the case. In matters of technical development open pit metal mines have usually been in advance of stone quarrying, and innovations—for example, the power shovel—have commonly spread from the former to the latter, rather than in the reverse direction. At the opening of our period, in 1900, when large scale power operations were already in progress on the Mesabi iron ore range, the quarrying of crushed stone was still predominantly a matter for hand labor and animal haulage.[114] The reason for this backwardness is not hard to find. Stone occurs in many places, and it is expensive to transport. Hence quarrying operations were, and to a large extent still are, conducted on a comparatively small scale: for quarries make up in number what they lack in size. Many of them operate only intermittently. To be sure, two developments have increased the scale, and have led to the mechanization, of quarrying operations in recent decades. One is the appearance of large, but highly localized, demands for crushed limestone, especially for cement plants. The other development is the demand for road material occasioned by the amplification and extension of the highway network.

For breaking, the crushed stone industry depends heavily upon the use of explosives, and for this reason extensive drilling is necessary. It has been estimated that in the days of hand drills as much as three quarters of the labor involved was occupied in drilling blast holes.[115] In 1900 hand drilling was still common.[116] By the first decade of the present century, however, piston drills, powered first by steam and then by compressed air, were making rapid headway.[117] Such drills were a great improvement over the hand drills formerly in use, but were rather slow in operation, and were limited to depths of 20 to 30 feet. Where deeper bodies of rock had to be broken, several benches were necessary.[118] To

[114] Kantor and Saeger, *Crushed-Stone Industry*, pp. 23-24.
[115] Nighman and Kiessling, *Rock Drilling*, p. 2.
[116] Kantor and Saeger, *Crushed-Stone Industry*, p. 34.
[117] See p. 119 above.
[118] I.e., the rock had to be removed in successive layers.

allow thicker layers of rock to be broken in a single operation, and to furnish the new power loading equipment with an adequate supply of broken stone, deeper drilling was needed. The answer was the power churn drill, introduced about 1912.[119] This instrument was developed originally for drilling oil wells, and is still known as the well drill. It requires a derrick, and can be used only vertically, but will drill holes up to six inches in diameter and several hundred feet deep if necessary. It consists essentially of a heavy bar attached to a beam, the latter actuated in a seesaw fashion by steam power. The power churn drill is cumbersome and, like the piston drill, somewhat slow in operation. For deep holes its use is still necessary, but for faces up to 40 feet in height. the hammer or drifter drill, which is light in weight and rapid in operation,[120] is now preferred. Hammer drills suitable for deep drilling in stone are essentially a product of metallurgical advance; they require long, hollow drill steels, which were not available until about 1917.[121]

The next operation, blasting, often has to be carried out in two stages. For if the primary blast fails to lead to a degree of fragmentation sufficient to allow of loading and crushing, then secondary blasting must be undertaken to break down the larger pieces of rock to an appropriate size. By using more explosive per ton of rock, and drilling a larger number of holes, the amount of secondary blasting required can be reduced to a minimum. Thus a nice choice exists between an elaborately prepared blast, in which almost complete fragmentation is achieved in a single operation, and a less elaborate drilling and blasting program, after which considerable secondary breaking may be necessary. In large crushed stone operations the tendency has been in the direction of more elaborate primary blasts and less secondary breaking. With a wide range of explosives available, and a willingness to drill as many as a thousand holes for a single blast, it has been found economical to break down several hundred thousand tons of rock in a single operation. Naturally such projects are possible only with the use of the power shovel and large capacity crushing equipment. Nor would they be worth while in the absence of a local demand for the stone on a scale unknown forty years ago.

119 Nighman and Kiessling, *Rock Drilling,* p. 15.
120 See above, p. 121.
121 Nighman and Kiessling, *Rock Drilling,* p. 77.

Once the rock has been broken, it must be loaded for transportation to the crusher. Steam shovels, which were first used for stripping overburden, came into use for loading stone about the end of the first decade of the present century.[122] The early shovels, originally developed for iron ore mining and general excavation work, were of course of the railroad type. However, the lack of flexibility and the trouble and delay involved in shifting track were great disadvantages, and the potentialities of power loading were not fully realized until the full-revolving shovel mounted on caterpillar treads appeared during the second decade. Moreover, there was a continuous increase in the capacity of shovels. After 1920 electric power was applied to the shovel; occasionally even gasoline and Diesel engines have been used.

Haulage from quarry to crusher is still commonly a matter of rail transportation, and the tendency has been for narrow gauge to be replaced by standard railroad equipment. Within the last two decades the motor truck has sometimes been adopted because of its great flexibility.

Mechanical crushing was already standard practice in stone quarries at the opening of the present century. Since then there has been a marked rise in the capacity of crushing plants, apparently induced by the increased efficiency of loading and transportation systems. The amount of secondary breaking has also been reduced through the construction of crushers with larger openings.

Dimension Stone

Dimension stone is a general term applied to all stone which is shaped or hewn, as for building, curbing, flagging, etc. Although underground marble and limestone quarries exist, most dimension stone comes from open pit enterprises. Overburden is removed by steam shovel or hydraulic methods and the rock is then cut layer by layer. Blasting is rarely employed because it tends to shatter the stone and produce undesired fragmentation. Where blasting is necessary, black powder rather than dynamite is used.

In marble, limestone and sandstone quarries the rock is cut in long rectangular blocks by a channeling machine. This piece of equipment is mounted on rails and driven by steam or electricity; it cuts a long vertical slit with a reciprocating three- or five-barred

[122] Kantor and Saeger, *Crushed-Stone Industry,* p. 50.

chisel-like steel.[123] Final separation from the solid rock is achieved by the driving of wedges.

Granite is too hard to be cut in this fashion, and for this rock other methods must be employed. Usually long rows of closely spaced holes are drilled, and wedges are then driven into the openings.

During the early part of the period we are discussing, slate was cut by channeling machines; these, however, are apt, even when specially designed, to produce cracks or undesired fragmentation. Since 1928 more and more slate has been quarried with the use of wire saws.[124] The wire saw consists of an endless steel cable three sixteenths to a quarter of an inch in diameter, composed of three strands, and ranging in length from a few hundred feet to half a mile. It is brought in contact with the rock face or stone to be cut by an elaborate system of pulleys, and its tension must be carefully regulated. The saw is commonly driven by electricity, and its cutting action is purely abrasive, so that there is no risk of undesired fragmentation. Often water and sand are injected into the cut to hasten the abrasive action of the saw. Essentially an innovation of the last two decades, the wire saw is used for dressing limestone, marble and sandstone, but in actual quarrying it has not yet superseded the channeling machine to any important extent, except in the case of slate.

The dressing of stone, sometimes carried on close to the quarry and sometimes at a distance, involves a great variety of processes which differ according to the type of stone and the use for which it is intended. Stone dressing, however, is a manufacturing operation, and falls outside the scope of this study.

123 For a description, see Oliver Bowles, *The Stone Industries* (McGraw-Hill, 1934), pp. 46-52.

124 *Ibid.*, pp. 255-60.