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NATIONAL RESEARCH PROJECT
on
Reemployment Opportunities and Recent Changes
in Industrial Techniques

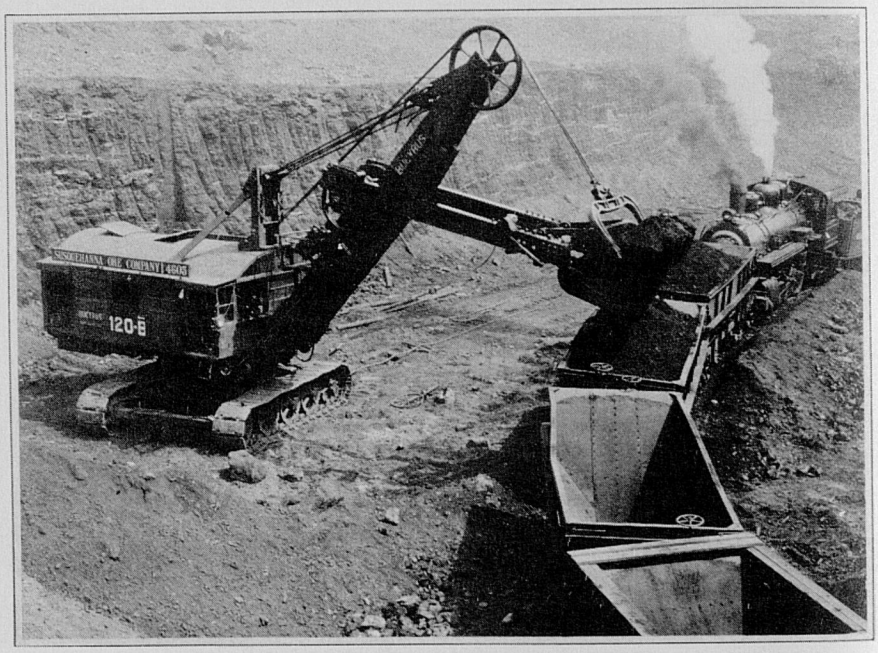
DAVID WEINTRAUB
Director

In cooperation with

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

R. R. Sayers, Director

Mineral Technology and Output Per Man Studies
O. E. Kiessling, Economist in Charge



LOADING IRON ORE AT AN OPEN-PIT MINE

The power shovel, one of the most effective pieces of mining machinery, is used in loading more than half of the iron ore produced in the United States. The adoption and improvement of these loading machines have greatly reduced unit labor requirements in iron mining.



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machines have

TECHNOLOGY, EMPLOYMENT, AND OUTPUT PER MAN IN IRON MINING

by

N. Yaworski, O. E. Kiessling,
C. H. Baxter, Lucien Eaton,
and E. W. Davis

WORK PROJECTS ADMINISTRATION, NATIONAL RESEARCH PROJECT
In cooperation with
DEPARTMENT OF THE INTERIOR, BUREAU OF MINES
Report No. E-13
Philadelphia, Pennsylvania
June 1940

THE WPA NATIONAL RESEARCH PROJECT ON REEMPLOYMENT OPPORTUNITIES AND RECENT CHANGES IN INDUSTRIAL TECHNIQUES

Under the authority granted by the President in the Executive Order which created the Works Progress Administration, Administrator *Harry L. Hopkins* authorized the establishment of a research program for the purpose of collecting and analyzing data bearing on problems of employment, unemployment, and relief. Accordingly, the National Research Program was established in October 1935 under the supervision of *Corrington Gill*, Assistant Administrator of the WPA, who appointed the directors of the individual studies or projects.

The Project on Reemployment Opportunities and Recent Changes in Industrial Techniques was organized in December 1935 to inquire, with the cooperation of industry, labor, and governmental and private agencies, into the extent of recent changes in industrial techniques and to evaluate the effects of these changes on the volume of employment and unemployment. *David Weintraub* and *Irving Kaplan*, members of the research staff of the Division of Research, Statistics, and Finance were appointed, respectively, Director and Associate Director of the Project. The task set for them was to assemble and organize the existing data which bear on the problem and to augment these data by field surveys and analyses.

To this end, many governmental agencies which are the collectors and repositories of pertinent information were invited to cooperate. The cooperating agencies of the United States Government include the Department of Agriculture, the Bureau of Mines of the Department of the Interior, the Bureau of Labor Statistics of the Department of Labor, the Railroad Retirement Board, the Social Security Board, the Bureau of Internal Revenue of the Department of the Treasury, the Department of Commerce, the Federal Trade Commission, and the Tariff Commission.

The following private agencies joined with the National Research Project in conducting special studies: the Industrial Research Department of the University of Pennsylvania, the National Bureau of Economic Research, Inc., the Employment Stabilization Research Institute of the University of Minnesota, and the Agricultural Economics Departments in the Agricultural Experiment Stations of California, Illinois, Iowa, and New York.

Since September 1, 1939, the Project has been sponsored by the National Resources Planning Board, Executive Office of the President, Washington, D. C.

FEDERAL WORKS AGENCY
WORK PROJECTS ADMINISTRATION
1734 NEW YORK AVENUE NW.
WASHINGTON, D. C.

F. C. HARRINGTON
COMMISSIONER OF WORK PROJECTS

June 8, 1940

Colonel F. C. Harrington
Commissioner of Work Projects

Sir:

The report herewith transmitted deals with the effects of technological changes on employment in the iron-mining industry. In 1937 this industry employed about 26,000 wage earners who produced almost as much iron ore as required 60,000 wage earners in 1917. The increasing productivity of labor was accelerated during the period since 1920 and was the chief factor in the large decline of employment. There were improvements in drilling and blasting and haulage methods. Mechanical loading was introduced at underground mines and was improved at open-pit mines, where it already existed, by the addition of caterpillar traction and the substitution of electric power for steam. These and the growing importance of open-pit mining, the concentration of production in larger mines and in areas with higher productivity, and the increased use of electric power generally have by far offset the tendency of productivity to decline as a result of depletion of the richer ore deposits.

Unemployment in iron-mining districts has been relatively larger than in the rest of the country. This has been true not only in depression years but also in years when mining activity was at a comparatively high level. Iron-mining counties in the important producing State of Minnesota showed higher levels of unemployment than other counties in the State, and a larger proportion of the population in these counties was forced onto the relief rolls even in fairly prosperous years. Seasonal lay-offs during the winter suspension of open-pit operations in the Lake Superior District, the largest iron-ore-producing area in the country, are an additional factor complicating the

problem of relief. The mining regions, moreover, offer very little in the way of alternative methods of gaining a livelihood. Practically all of the salable timber has long been cut out, and rigors of climate and the nature of the soil do not permit any extensive resort to agriculture.

We cannot expect any sizable increase in iron-mining employment even if an armament program were to result in a large increase in the demand for iron ore. To reach the 1917 output of 75 million tons, only about one-half as many men would be required now as in 1917.

Respectfully yours,

Corrington Gill

Corrington Gill
Assistant Commissioner

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PREFACE

In 1880 it took a man a whole working day to produce a ton of iron ore. In 1915, working a shorter day, he was able to produce five times as much. Today, when the working shift is a fifth shorter than in 1915, the average output per man-shift is about 10 tons. These changes in labor requirements per unit of product in the iron-mining industry are the result of a variety of factors which operated with varying intensity in different periods of the industry's history.

Prior to the World War the principal cause of the rise in the average output per man was the discovery and development of richer and more easily accessible ore deposits, chiefly in the Lake Superior District. Extraction of these ores, mainly by open-pit methods, required much less labor per ton than in the older underground mines of the Northeastern District. The Lake Superior District therefore grew rapidly in importance, and since 1912 Minnesota alone has been producing more than 60 percent of the total national iron-ore output.

Since the early 1920's, the rapid increases in output per man have been primarily the result of technological improvements. The largest gains in productivity were made at open-pit mines. The introduction of full-revolving shovels and of caterpillar traction, the substitution of electric power for steam in drilling, loading, and haulage, the adoption of improved types of churn drills, the improvement in the design and construction of mine cars, the introduction of dump spreaders and track shifters, and the recent use of belt conveyors, tractors, and trucks have all contributed to triple the output per man-hour at open-pit mines in the last 20 years despite the increasing natural handicaps represented by the ever deeper overburdens which had to be removed, the increased depth of pits, and the leaner ores.

At underground mines, increases in productivity have been more gradual than at open-pit mines. Output per man-hour rose from 0.35 gross ton in 1917 to 0.69 in 1937. The largest savings have been effected by mechanization of loading, primarily by the use of scraper loaders. Gains also resulted from improvements in drilling and blasting, from the use of more efficient electric locomotives and larger, more durable, and better-designed mine cars, and from the better adaptation of equipment and methods to natural conditions.

The changes in average output per man for the iron-mining industry as a whole were also greatly affected by changes in the number and kinds of

mines comprising it. Competition within the industry, which in part takes the form of cost competition among mines owned by the same company, and the technical advantages inherent in large-scale mining operations constitute an important aspect of the rising trend of labor productivity in the past half-century. Underground mines, for example, have usually been at a disadvantage in competing with open-pit mines unless they were favored by some compensating circumstance, such as a large deposit of high-grade ore that did not require concentration. The difficulties of underground mines were greatly intensified in the post-war period when open-pit mines adopted many new improvements and when the demand for iron ore had slackened. But for the adoption of scraper loaders and other improvements of underground-mining techniques, many of these mines would have been unable to continue operations. Similarly, efforts to overcome the problems resulting from increasing depth of open-pit mines have led to the development of such new mining techniques as the use of belt conveyors, and attempts to overcome the disadvantages of mining small ore deposits have recently led to the development of small, self-contained power shovels for loading and to the use of motor trucks for haulage and dumping.

Part of the labor savings at both open-pit and underground mines in the post-war period is also attributable to the continued concentration of production in the larger and more efficient operations in all areas. While production increased ninefold from 1880 to 1937, the number of producing mines declined about 80 percent with the rapid growth in the size of mining operations. At present more than two-fifths of the total output comes from the one-twentieth of the mines that produce more than 1 million tons annually. Mines of this size are mostly open-pit operations, and the output per man-hour in open-pit mines of such size is twice that of open pits which produce from 500,000 to 1 million tons annually.

So long as production expanded at a faster rate than output per man, employment continued to increase. But the growth of iron-ore production reached a turning point during the second decade of this century. Employment at iron mines was at its peak in 1917. Today, the Nation's iron-ore requirements can be supplied by fewer than half the number of workers needed 20 years ago, and the trends in the factors which have made this possible are continuing. One of these factors is that the demand for iron ore has slackened because of a retardation in the growth of iron and steel production. Another important factor is the increased use of scrap. Unlike the product of almost all other industries, the

product of metal mines is not entirely destroyed in consumption but can be used repeatedly. It has been estimated that about two-thirds of the iron that finds its way into iron and steel products returns after 10 to 30 years in the form of scrap and is available for re-use in a much purer form than iron ore. The total stock of iron and steel goods is being constantly augmented and represents a growing potential source of iron and steel scrap that may be used in place of iron ore. The old ferrous scrap consumed annually in the iron and steel industry during 1935-38 had an iron content equivalent to about 29 million tons of iron ore which, had it been mined at the prevailing average labor productivity, would have required the work of about 12,500 men.

This report is one of a series of studies conducted by the National Research Project in cooperation with the United States Bureau of Mines under the direction of O. E. Kiessling. It was prepared by N. Yaworski, of the National Research Project; O. E. Kiessling, of the Bureau of Mines; C. H. Baxter, of the Michigan College of Mining and Technology; Lucien Eaton, of the Copper Range Co.; and E. W. Davis, of the Mines Experiment Station, University of Minnesota. The manuscript was edited and prepared for publication under the direction of Edmund J. Stone.

DAVID WEINTRAUB

PHILADELPHIA
June 7, 1940

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Grateful acknowledgment is also made to WPA National Research Project staff members who carried out important assignments in the conduct of the study. The preliminary survey of the technical information available and the exploratory examination of the statistical data at the inception of the study were conducted under the supervision of Pomeroy C. Merrill, Mining Engineer, now engaged in mining activities in the Philippine Islands. Charles R. M. Tuttle, Asst. Research Engineer, was also associated with the survey in its early stages and rendered valuable assistance in preparing the statistics. Responsibility for the accuracy of the statistical compilations fell chiefly upon Merle E. Cadle and Ruth E. Good, who were associated with the study from its beginning. Mr. Cadle also assisted in the conduct of special background investigations. Harry P. Sweeny, Senior Technical Advisor (now Mining Engineer, Consumers' Counsel Division, Office of the Solicitor, United States Department of the Interior), assembled much of the material on improvements in drilling and blasting and prepared a preliminary review of the subject. Many helpful suggestions were received from C. E. Nighman, Consulting Mining Engineer (now Mineral Economist, General Land Office, United States Department of the Interior), whose lifetime of mining experience provided a valuable fund of information. L. N. Plein, Senior Engineer-Economist, National Bituminous Coal Commission (now Engineer

Examiner, Reconstruction Finance Corporation), assembled much of the historical data relating to the mechanization of loading at underground mines. Special work in reviewing the literature on iron-ore reserves and in the compilation of table A-23 was done by Robert L. Kiessling, Asst. Mineral Economist. Cooke Settle, Asst. Mineral Economist, was largely responsible for the lay-out and preparation of the charts, diagrams, and maps. Wilhelmina F. Whiting, Essie Mae Steuart, and Helen Yaworski completed special assignments connected with the preparation of the manuscript.

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For an opportunity to visit the iron mines in the Lake Superior District and to obtain first-hand information about new technological improvements, thanks are due to many mining companies, especially to the officials and mining captains of the Oliver Iron Mining Co.; the Cleveland-Cliffs Iron Co.; the M. A. Hanna Co.; Pickands, Mather & Co.; Oglebay, Norton & Co.; the Montreal Mining Co.; and Butler Brothers.

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The cooperation of the following concerns which contributed the photographs that were used to illustrate the report is cordially acknowledged: Bucyrus-Erie Co.; Marion Steam Shovel Co.; Sullivan Machinery Co.; Lima Locomotive Works, Inc.; Nordberg Manufacturing Co.; Differential Steel Car Co.; the Cleveland-Cliffs Iron Co.; and the publishers of *Skillings' Mining Review*. Photographic material was also furnished by the United States Bureau of Mines.

CHAPTER I

INTRODUCTION*

Since the World War the growth of iron-ore production in the United States has been arrested, while developments within the iron-mining industry have increased output per man at a faster rate than before. The result has been a major reduction in employment in iron mining, and technological changes that affect the output per worker have acquired a new significance.

The principal objective of this report is to trace the important developments that have contributed to changes in the volume of employment in the iron-mining industry over the past half-century, to evaluate the major factors influencing such changes, and to estimate the probable employment trends during the next 10 years and over a longer period. Particular attention is paid to the role of past and prospective changes in industrial techniques.

Employment opportunities[1] are a function of two factors: the total quantity of production and the average output per unit of labor. Thus in this analysis of past and prospective changes in employment opportunities in iron mining two sets of influences are examined: one group that affects output per worker at iron mines and another that affects the volume of iron ore produced. Changes in average output per worker have been influenced strongly by physical conditions of mining, such as depth and character of ore bodies and the discovery and exploitation of new and more favorable ore deposits, by prevailing techniques of mining, and by other factors.[2] Changes in the volume of iron-ore production have been affected by many economic as well as technological factors, operative mainly beyond the limits of the iron-mining industry.

Labor productivity is viewed as a determinant of employment opportunities and as an indicator of changes in mineral technology and natural mining conditions. Accordingly, considerable attention has been devoted

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[1]The term "employment opportunities" as used in this report refers to the total number of man-hours of available work. Total man-hours are used wherever possible, but for the period prior to 1915 only man-shifts were available. The length of shift, however, has varied during the period studied, and this feature must be taken into consideration.

[2]Changes in average output per man in the iron-mining industry as a whole are determined not only by changes in labor productivity among groups of mines classified according to some significant common characteristic, such as geographic location or method of mining, but also by changes in the proportionate share of the total output produced by each group and by individual mines within each group, since there are wide differences in output per worker among individual operations.

to an analysis of trends in average output per worker[3] - or its reciprocal, labor requirements per unit of product - and to the major factors affecting it. There were available production, employment, and other data that permitted an analysis of changes in output per man for important areas and mining methods.

The iron-mining industry as covered in this survey comprises all those functions performed at iron mines that are necessary to produce iron ore of merchantable grade. These include development work preparatory to the actual extraction of ore, such as stripping overburden at open-pit mines and sinking shafts and driving tunnels in underground mines;[4] all the activities associated with actual mining, such as loosening, loading, transporting, and hoisting ore and waste materials; and ore beneficiation[5] where it is necessary to make the product merchantable. For the purposes of this study, iron mining ends when the ore (either in its natural state or after beneficiation) is loaded into railroad cars for shipment either directly to consumers or to ore docks or other shipping transfer points.[6]

Chapter II presents briefly the record of trends in production, employment, and average output per man since 1880, for the United States as a whole and for the important domestic iron-ore-producing areas.

Chapter III describes the major factors that have accounted for the rise in output per worker in the past half-century despite the gradual exhaustion of the most accessible and richest ore deposits in each major producing area. Pertinent statistical information is also presented regarding the shift of operations to areas with more easily mined

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[3]The measures of average output per man are the ratios of the total production to total employment. Production as used in this report is in gross tons of merchantable iron ore, unless otherwise stated. The metallic iron content of iron ore has remained remarkably uniform throughout the 58-year period analyzed, and for practical purposes the output of merchantable ore reflects the trend of production of iron in ore. Employment is in terms of total man-shifts worked in the long-time analysis for 1880-1937, and in terms of man-hours in the more detailed analysis for the shorter period 1915-37. Only direct labor is included, such as that of men working in mines, beneficiation plants, and all surface shops and plants connected with the mining or primary processing of crude ore. Man-shifts or man-hours worked by administrative and clerical employees are thus excluded. Unless otherwise stated, "employment" is to be understood as referring only to wage earners.

[4]Some of this development work was done by contractors whose employees were reported to the U. S. Bureau of Mines by either the contractors themselves or the mining companies for whom the work was done.

[5]Beneficiation is any method of ore treatment for the purpose of improving its quality. The process may simply improve the physical character of the ore as in crushing large lumps into smaller ones, or it may consist of "concentrating" the ore whereby the proportion of metallic iron is increased by removing some of the waste material.

[6]It is customary for the underground mines in the Lake Superior region to continue "operations" during the winter and to stock the ore in huge piles near the mines. The Great Lakes are frozen over during this period, and the mined ore cannot be shipped by water until spring. The ore must then be loaded from stock piles. Also, at many open-pit operations nonmerchantable lean ore is regularly stockpiled or concentrated. These functions are considered a part of the iron-mining industry. On the other hand, improvements in the transport of ore beyond the mines are not considered a part of the iron-mining industry, but some of these significant improvements are reviewed briefly in appendix B.

and higher-grade deposits and regarding the concentration of production in larger and more fully mechanized mines.

Chapters IV and V discuss in some detail important factors affecting the trends of production, employment, and output per man at open-pit and underground mines respectively. Special attention is given to the progress of technology in overcoming physical difficulties and in increasing output per man.

The outlook for production, employment, and output per man in iron mining is considered in chapters VI and VII. Chapter VI analyzes the prospects for the development and expansion of iron-ore beneficiation and the greater utilization of low-grade ore reserves. In chapter VII the probable trend of employment over the next 10 years and longer is considered by estimating the future trends of output per man and iron-ore production. Estimates regarding the future trend of output per worker take into account the character and availability of ore reserves, as well as prevailing and potentially applicable techniques of mining and beneficiation. The outlook for iron-ore production is estimated by an appraisal of prospects for the continuation of past trends in demand and for probable new developments in the production and consumption of iron and steel products and ferrous scrap.

CHAPTER II

LONG-TIME TRENDS IN EMPLOYMENT, PRODUCTION, AND OUTPUT PER MAN*

In this chapter, the interest is centered primarily in the more enduring changes in production and output per man as they have affected employment opportunities of workers attached to the iron-mining industry in the past. Accordingly, the trends are examined in the broad perspective afforded by more than half a century, beginning with the census year 1880, the first for which reliable employment data are available.

RISE AND DECLINE OF EMPLOYMENT IN IRON MINING

The iron mines of the United States, including ore-beneficiating plants at the mines, afforded employment in 1937 to 25,945 wage earners and about 2,000 salaried employees,[1] and produced 72 million gross tons of merchantable ore. Fifty-seven years earlier the number of wage earners employed in iron mining had exceeded by about 9,000 the number in 1937, although the quantity of iron ore produced had been only one-tenth as large. (See table 1 and figure 1.) However, this failure of employment to keep pace with the growth in production did not characterize the entire period. The World War marked a definite turning point in the trends.

For more than a quarter of a century before the World War, employment in iron mining was in general increasing, from about 35,000 wage earners in 1880 to 43,400 in 1915 and to a record peak of 60,600 in 1917.[2] This rise in employment accompanied a rapid expansion of production and occurred in spite of an increase in average output per worker. Although labor productivity advanced from 0.9 gross ton of merchantable ore per man-shift in 1880 to 4.7 gross tons in 1915, an increase of 430 percent, the growth in production was 680 percent - from 7.1 million gross tons to 55.5 million.

The post-war period was marked by a sharp reversal of the previous employment trend. Although iron-mining activity was characterized by extreme fluctuations, as in 1932 when employment dropped to the lowest

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[1] These data exclude employees engaged in handling iron ore after it leaves the mines - in transporting ore by rail and water from mines to smelters and in loading and unloading ore at the Lakes ports, at stock piles beyond the mines, and at blast furnaces.

[2] The number of men employed during the World War, especially in 1916 and 1917, was unusually high and should not be considered a normal labor force.

Table 1.- EMPLOYMENT AT IRON MINES IN THE UNITED STATES, BY WAGE EARNERS AND SALARIED EMPLOYEES, 1880-1937

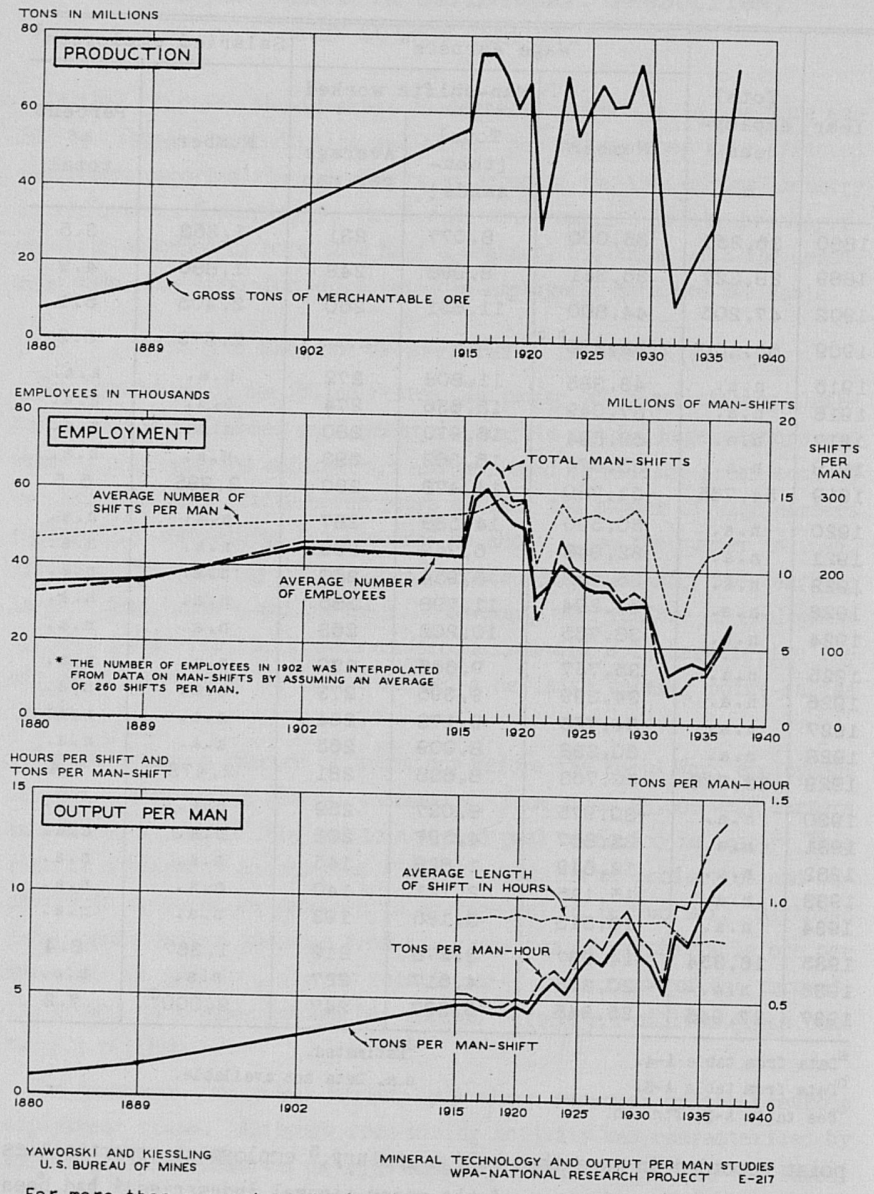
Year	Total employees	Wage earners[a]			Salaried employees[b]	
		Number	Man-shifts worked		Number	Percent of total
			Total (thousands)	Average per man		
1880	36,253	35,000	8,077	231	1,253	3.5
1889	38,227	36,341	8,998	248	1,886	4.9
1902	47,205	44,800	11,651	260	2,405	5.1
1909	55,100	52,230[b c]	n.a.	n.a.	2,870	5.2
1915	n.a.	43,385	11,808	272	n.a.	n.a.
1916	n.a.	57,049	15,636	274	n.a.	n.a.
1917	n.a.	60,594	16,970	280	n.a.	n.a.
1918	n.a.	55,674	16,302	293	n.a.	n.a.
1919	54,765	51,780	14,478	280	2,985	5.5
1920	n.a.	50,590	14,538	287	n.a.	n.a.
1921	n.a.	32,348	6,749	209	n.a.	n.a.
1922	n.a.	35,758	8,954	250	n.a.	n.a.
1923	n.a.	41,294	11,798	286	n.a.	n.a.
1924	n.a.	38,765	10,202	263	n.a.	n.a.
1925	n.a.	35,757	9,666	270	n.a.	n.a.
1926	n.a.	34,399	9,395	273	n.a.	n.a.
1927	n.a.	34,755	9,178	264	n.a.	n.a.
1928	n.a.	30,238	8,009	265	n.a.	n.a.
1929	33,236	30,763	8,638	281	2,473	7.4
1930	n.a.	30,975	8,037	259	n.a.	n.a.
1931	n.a.	22,867	4,597	201	n.a.	n.a.
1932	n.a.	12,649	1,828	145	n.a.	n.a.
1933	n.a.	15,125	2,121	140	n.a.	n.a.
1934	n.a.	16,513	3,186	193	n.a.	n.a.
1935	16,354	14,987	3,278	219	1,367	8.4
1936	n.a.	20,306	4,617	227	n.a.	n.a.
1937	27,945	25,945	6,397	247	2,000[d]	7.2

[a] Data from table A-4.
[b] Data from table A-3.
[c] See table A-3, ftn. bb.
[d] Estimated.
n.a. Data not available.

point recorded in more than half a century,[3] employment opportunities in iron mining (as in some of the major mineral industries)[4] had been drastically curtailed long before the advent of the great depression. By 1929 the number of men employed had declined 29 percent below the 1915 level, despite an increase of 32 percent in production, for average output per man-shift in the meantime had grown 80 percent.

[3] The number of wage earners and the number of man-hours worked in 1932 were only 41 and 21 percent respectively of the numbers in 1929. (See table A-4.)
[4] Notably the coal and nonferrous-metal industries.

Figure 1.- PRODUCTION OF MERCHANTABLE ORE, EMPLOYMENT, AND OUTPUT PER MAN IN IRON-ORE MINING IN THE UNITED STATES, 1880-1937

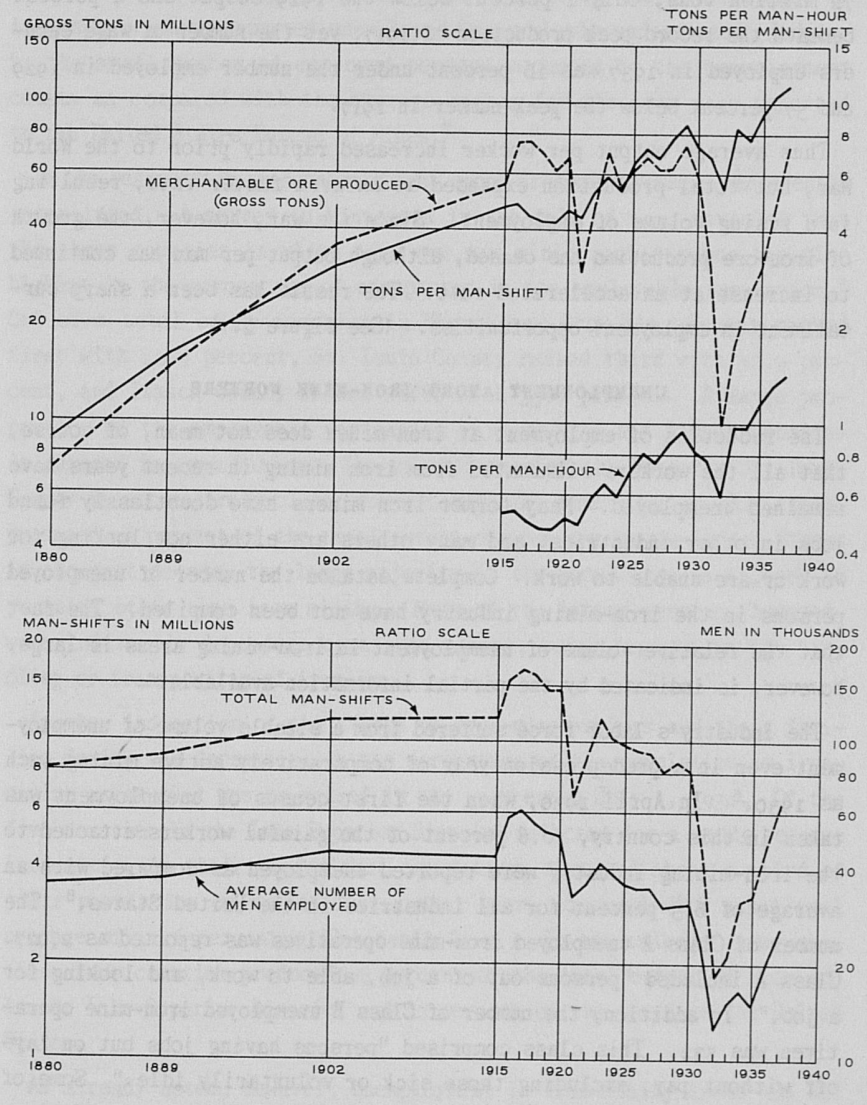


YAWORSKI AND KIESSLING
U. S. BUREAU OF MINES

MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES
WPA-NATIONAL RESEARCH PROJECT E-217

For more than a quarter of a century before the World War, employment in iron mining rose almost steadily, reaching a peak of over 60,000 employees in 1917; but by 1929 it had declined to half the 1917 level and three-fourths the 1923 level, with production only 3 percent below that of 1917 and 5 percent above that of 1923. Prior to the war period iron-ore production had increased more rapidly than average output per worker; the result was a rising volume of employment. In the post-war period, however, the growth of iron-ore production ceased, while output per man increased more rapidly than before; the result was a sharp curtailment of employment. (See table A-4 for data.)

Figure 2.- CONTRASTING RATES OF CHANGE IN PRODUCTION, EMPLOYMENT, AND OUTPUT PER MAN IN IRON-ORE MINING IN THE UNITED STATES, 1880-1937



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MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES
WPA-NATIONAL RESEARCH PROJECT E-218

Prior to the war period, average output per worker increased rapidly; but total production rose even more rapidly, resulting in a rising volume of employment. Since the war, however, the growth of iron-ore production has ceased; but output per man has continued to increase at an accelerated rate, resulting in sharply curtailed employment opportunities. The curves in this chart are plotted on a semilogarithmic scale so that the percentage-change relationships may be judged from a comparison of the relative slopes of the lines. (See table A-4 for data.)

The latest year for which complete data are available, 1937, was one of unusually high production. The quantity of iron ore produced was 72 million tons, only 1 percent below the 1929 output and 4 percent beneath the record peak production of 1917; yet the number of wage earners employed in 1937 was 16 percent under the number employed in 1929 and 57 percent below the peak number in 1917.

Thus average output per worker increased rapidly prior to the World War, but total production expanded at an even faster rate, resulting in a rising volume of employment. Since the war, however, the growth of iron-ore production has ceased, although output per man has continued to increase at an accelerated rate. The result has been a sharp curtailment in employment opportunities. (See figure 2.)

UNEMPLOYMENT AMONG IRON-MINE WORKERS

The reduction of employment at iron mines does not mean, of course, that all the workers eliminated from iron mining in recent years have remained unemployed. Many former iron miners have doubtlessly found jobs in other industries, and many others are either not looking for work or are unable to work. Complete data on the number of unemployed persons in the iron-mining industry have not been compiled. The fact that the relative volume of unemployment in iron-mining areas is large, however, is indicated by the partial information available.

The industry's labor force suffered from a sizable volume of unemployment even in a predepression year of comparatively active mining such as 1930.[5] In April 1930, when the first census of unemployment was taken in this country, 10.6 percent of the gainful workers attached to the iron-mining industry were reported unemployed as compared with an average of 6.5 percent for all industries in the United States.[6] The number of Class A unemployed iron-mine operatives was reported as 2,027. Class A included "persons out of a job, able to work, and looking for a job." In addition, the number of Class B unemployed iron-mine operatives was 532. This class comprised "persons having jobs but on layoff without pay, excluding those sick or voluntarily idle." Some of the Class B persons may have found employment later in the year - since

[5] The year 1930 may be taken as near normal from the standpoint of production. The quantity of iron ore produced in 1930 was 58,408,864 gross tons as compared to an annual average of 61,739,217 gross tons in the 9-year post-war period, 1922-30. The average number of employees at iron mines and beneficiating plants, exclusive of salaried employees, as reported to the U. S. Bureau of Mines for 1930 (30,975), was practically the same as in 1929 (30,763), when the production was 73,027,720 gross tons; however, the average number of shifts worked per man in 1930 was 259 compared with 281 in 1929.

[6] *Fifteenth Census of the United States: 1930*, "Unemployment" (U. S. Dept. Com., Bur. Census, 1932), II, 13.

the peak of employment at iron mines, especially in the Lake Superior District where the bulk of the industry is concentrated, is not usually reached until after April of each year. However, the total number of iron-mine workers reported unemployed was probably understated, judging by the small number of employed persons reported by the unemployment census as compared with the average number for the year 1930 reported to the United States Bureau of Mines.[7]

In the years after 1930 unemployment among iron-mine workers was greatly intensified. A survey in Minnesota in the fall of 1932 revealed that the three counties in which iron ore was mined ranked among the five highest in the percentage of unemployed in the employable population.[8] Out of a total of 87 counties in Minnesota, Crow Wing County ranked first with 42.9 percent, St. Louis County ranked third with 36.9 percent, and Itasca County ranked fifth with 35.7 percent. A large proportion of the employable population in Crow Wing and Itasca Counties is engaged in iron mining. The significance of the data for St. Louis County is not entirely clear; for although the iron mines in this county produced 46 percent of the total output of iron ore in the United States in the past decade, the large majority of the population is engaged in pursuits other than iron mining. Many of the latter persons, however, were indirectly dependent upon iron mining, being engaged in the handling or transporting of iron ore.

Another indication of the status of iron-mine workers and their families during the depression is the percentage of the population in iron-mining areas that was on relief in the year ended July 1, 1934. Of the five counties in the Lake Superior District selected for a study because iron-mining is their predominant occupation, four had about a third of their population on relief during that year, compared with a national average of 11.6 percent. (See table A-27.) In the calendar year 1934 these four counties produced 26 percent of the total output of iron ore in the Lake Superior District and 22 percent of the total in the United States.

As already noted, however, unemployment in iron-mining areas has not been confined to depression years. Thus in the first post-depression

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[7] The unemployment census for April 1930 reported a total of 24,248 workers (excluding salaried officials) attached to the iron-mining industry, including *both employed and unemployed* persons. The average number of *employed* persons (also excluding salaried officials), as reported to the U. S. Bureau of Mines for the same year, was 30,975.

[8] Data were assembled through questionnaires sent to officers of counties, cities, villages, and townships. The replies were analyzed by the Industrial Commission of the State. See *Twenty-Fourth Biennial Report of the Department of Labor and Industry, 1933-34*, "Seventh Biennial Report of the Industrial Commission of Minnesota" (St. Paul, Minn., 1935), pp. 12-5.

year of high production, 1937, the proportion of unemployed in iron mining apparently was larger, at least in certain areas, than the average for all industries in the United States. This was indicated by the special unemployment census in November of that year. The number of persons registered as unemployed or emergency workers in five counties in the Lake Superior District represented 9.4 percent of the 1930 population of these counties as compared with 6.4 percent for all industries in all counties in the United States.[9] (See table A-28.) These five counties produced 33 percent of the Nation's 1937 iron-ore production.

Unemployment in areas where the most important iron mines are situated creates especially difficult social problems because of the scarcity of other means of earning a livelihood. The bulk of iron-mining activity is located in the Cutover Region of the Lake Superior District where virtually all the virgin timber was cut away long ago. This has eliminated lumbering as an important occupation; the only other practical alternative, agriculture, offers little opportunity for any considerable number of people because soil and climatic conditions are unfavorable.[10]

IRON-ORE PRODUCTION

Iron and steel and their chief raw material, iron ore, represent the very foundation of our mechanized civilization. The people of the United States consume more steel per capita than any other nation in the world,[11] which is a measure of this country's preeminence as an industrial nation.

Our present level of consumption and production of iron ore and its products, iron and steel, was largely attained in the 50-year interval between the Civil War and the World War. This period was characterized by a vigorous increase in population, rapid industrial expansion, and a phenomenal growth in rail-transportation facilities. In the 57 years between 1880 and 1937 iron-ore production increased approximately ninefold, from a little over 7 million gross tons to 72 million tons. Pig-iron production rose from almost 4 million tons to a little over 37 million, about 870 percent. Most impressive of all was the fortyfold increase in the production of steel, from about 1,250,000 gross tons in 1880 to 51,200,000 tons in 1937. (See figure 3.)

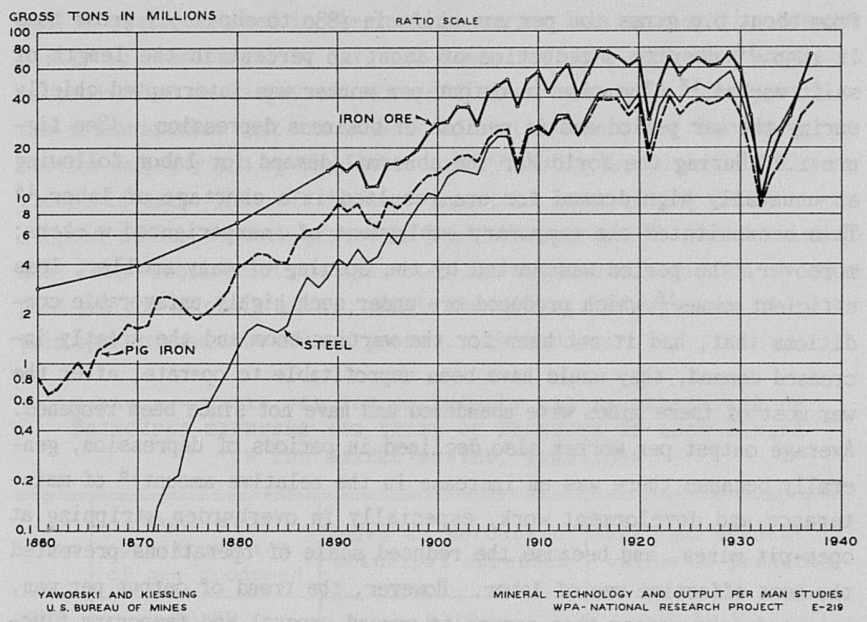
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[9] There is nothing to indicate that relative population changes after 1930 could account for any substantial part of this difference.

[10] See Carter Goodrich, Bushrod W. Allin, and Others, *Migration and Economic Opportunity* (Philadelphia, Pa.: University of Pennsylvania Press, 1936), pp. 164-201.

[11] In 1937, the first year since the beginning of the great depression in which production approached the 1929 level, the United States consumed 844 pounds of steel per capita. This compares with a per-capita consumption of 746 pounds in Belgium-Luxemburg, 548 in Great Britain and Germany, 318 in France, 298 in Japan, 259 in Russia, and 135 in Italy. *Steel*, Vol. 102, No. 1 (Jan. 3, 1938), p. 370.

Figure 3.- PRODUCTION OF IRON ORE, PIG IRON, AND STEEL IN THE UNITED STATES, 1860-1937



The decline of employment in the iron-mining industry after the World War, in contrast to a rising volume of employment in the preceding period, is partly explained by a retardation in the growth of production of iron and steel and their principal source - iron ore. Steel production has grown more rapidly than has pig-iron production; but since 1908 most of the steel has been made by the open-hearth process that uses much scrap iron and steel, thus replacing virgin iron from ore. (For data see table A-2.)

When the rates of increase in production are studied closely, it can be seen that the period of rapid growth ended with the World War. In the 29 years between 1880 and 1909 iron-ore production increased more than sixfold; but in the subsequent 28-year period, from 1909 to 1937, it rose only 39 percent. Likewise, pig-iron production advanced 573 percent in the 29 years preceding 1909, but in the following 28 years the rise amounted to only 44 percent; and steel production, which had increased eighteenfold in the period before 1909, rose only 114 percent in the later period.

The arrested demand for iron ore following the World War (more fully considered in chapter VII) was due to a slower growth in the consumption of iron and steel products, to an increase in the proportion of iron requirements supplied by scrap rather than by iron ore, and, to a lesser extent, to improved efficiency in the consumption of iron ore in iron and steel manufacture. Meanwhile, the ore required was produced with a constantly diminishing labor force.

RISE IN OUTPUT PER MAN

Average output per worker at iron mines increased almost steadily from about 0.9 gross ton per man-shift in 1880 to about 9.7 gross tons in 1937,[12] despite a reduction of about 20 percent in the length of shift worked.[13] The rise in output per worker was interrupted chiefly during the war period and in periods of business depression. (See figure 1.) During the World War the abnormal demand for labor following an unusually high demand for ore resulted in a shortage of labor.[14] This necessitated the temporary employment of inexperienced workers; moreover, the period was marked by the opening of many smaller, less efficient mines[15] which produced ore under such highly unfavorable conditions that, had it not been for the wartime boom and the greatly increased demand, they would have been unprofitable to operate; after the war most of these mines were abandoned and have not since been reopened. Average output per worker also declined in periods of depression, generally because there was an increase in the relative amount[16] of maintenance and development work, especially in overburden stripping at open-pit mines, and because the reduced scale of operations prevented the most effective use of labor. However, the trend of output per man, computed in a manner that serves to spread unusual and temporary fluctuations over a number of years, shows a continuous increase. (See figure 12.)

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[12]The average of 9.7 gross tons per man-shift in 1937 is the approximate trend value for that year, computed by the method of least squares applied to the period 1922-37. This average more truly represents the normal performance and spreads over a period of years the influence of unusual temporary fluctuations in the relative amounts of production and development work. In this report, however, the labor engaged in development work and other labor, which fluctuates more or less independently of the volume of production, could not be segregated and eliminated from the available employment statistics. Thus the actual output per man-shift in 1937 was 11.3 gross tons, equivalent to 0.09 man-shift per ton; but the relative amount of development work, especially overburden stripping at open-pit mines in Minnesota (which produced about 59 percent of the national output of merchantable ore), was unusually low. The computed trend of output per man-shift more nearly approaches the measure desired, for it serves to spread over a number of years the periodic additions to operating labor of labor engaged in other work. The period for which the trend of output per man was computed, 1922-37, covers 8 years of relatively high production and 8 years of relatively low production; it also includes approximately two cycles of fluctuations in the ratio of overburden stripping to ore produced which greatly affect output per man at open-pit mines.

[13]Reports of iron-mining companies to the U. S. Bureau of Mines indicate that the weighted average length of shift at iron mines in the United States has now been standardized at about 8 hours. (See table A-4.) During the war period it was about 9 hours, and in 1909 it had been 9.9 hours, according to the United States census report. (See *Thirteenth Census of the United States: 1910*, Vol. XI, "Mines and Quarries: 1909" [U. S. Dept. Com., Bur. Census, 1913], p. 248.) From incomplete data available for 1880 it appears that the average length of shift in that year was at least 10 hours.

[14]See *U. S. Steel News*, Vol. 2, No. 6 (June 1937), pp. 16-7.

[15]Note the increase in the number of producing iron mines during the World War period, as shown in table A-11.

[16]That is, in proportion to the amount of ore produced. Actually, the amount of overburden stripped at open-pit mines, for example, declined, but the quantity of ore produced dropped even more, resulting in an increase in the number of cubic yards of overburden removed per ton of ore produced. (See figure 18.)

The rise in average output per worker was largest in the post-war period; half of the tenfold increase in output per man-shift over the past 57 years occurred in the last 15 years. This acceleration was due partly to abandonment of marginal mines and more rapid concentration of production in larger and more efficient operations, and partly to the mechanization that was stimulated by the demand for increased production capacity and by high labor costs[17] during and directly following the World War. Many of the most important labor-saving devices were adopted during or soon after the World War period.[18] The decline in unit labor requirements is reflected in the general reduction in wages paid per ton of ore produced, and in the percentages wages are of either principal expenses or value of product. (See table 2.)

Table 2.- WAGES PER TON OF PRODUCT AND AS PERCENTAGE OF PRINCIPAL EXPENSES AND VALUE OF PRODUCTS IN IRON MINING IN THE UNITED STATES, 1889-1935[a]

Year	Wages paid per gross ton of ore produced	Wages as percent of principal expenses[b]	Wages as percent of value of products
1889	$0.89	61.9	38.9
1902	0.61	65.1	32.9
1909	0.57	56.0	27.1
1919	1.24	62.2	34.7
1929	0.55	52.9	20.7
1935	0.47	51.3	19.1

[a] Data are from table A-3.

[b] Principal expenses included are salaries, wages, contract work, supplies and materials, and fuel and purchased power.

[17] See editorial and other notes in the following issues of Vol. 114 (1922) of *Engineering and Mining Journal-Press*: No. 1 (July 1), p. 37; No. 3 (July 15), p. 119; No. 4 (July 22), p. 168; No. 5 (July 29), p. 212; No. 7 (Aug. 12), pp. 265-6, 300; No. 8 (Aug. 19), p. 345; No. 9 (Aug. 26), p. 357; No. 15 (Oct. 7), p. 653; No. 17 (Oct. 21), p. 707; No. 22 (Nov. 25), p. 925.

The average cost of common labor per day for iron mines of St. Louis County in Minnesota (which produces about half of the Nation's output) was as follows:

Year	Average cost per day	Year	Average cost per day
1914	$2.00 to $2.25	1926	$4.20
1915	2.00 to 2.25	1927	4.16
1916	2.00 to 2.60	1928	4.17
1917	3.40 to 4.00	1929	4.17
1918	4.15 to 5.38	1930	4.18
1919	4.84 to 5.33	1931	4.09
1920	4.00 to 5.33	1932	3.41
1921	2.75 to 4.00	1933	3.31
1922	2.75 to 3.75	1934	3.66
1923	3.75 to 4.20	1935	3.74
1924	3.75 to 4.20	1936	3.89
1925	4.20	1937	5.20

(See data of Ed Smith, Mine Inspector, St. Louis County, in John J. Craig, *Mining Directory of Minnesota, 1938*, Vol. XLI, No. 30 [Univ. of Minn., School of Mines Expt. Sta., May 1, 1938], p. 231.) Data for 1914-21 are for years beginning July 1.

[18] See "Iron Mining in the United States," *Engineering and Mining Journal*, Vol. 105, No. 2 (Jan. 12, 1918), p. 74.

CHAPTER III

MAJOR FACTORS INCREASING OUTPUT PER MAN*

The upward trend in output per man in the past half-century, briefly traced in the preceding chapter, is the net result of many closely related causes. The most important factor has been the concentration of production in mines having large, easily accessible, and high-grade ore deposits to which have been brought constantly improved techniques of mass production. Prior to the World War there was a more rapid relative growth of mining in the Lake Superior District, where the newly discovered iron ranges contained the richest and the most easily mined deposits. After the war, this geographic concentration virtually ceased, and the major factors in reducing labor requirements were an accelerated shift of production to the larger and more efficient mines in each area and a quickened rate of technological advance. An important aspect of these developments in both the pre-war and post-war periods has been the growth in open-pit mining.

GROWTH OF OPEN-PIT MINING

In the past half-century a large part of the gain in the average output per worker at iron mines in the United States was due to an increase in the proportion of the total output produced by open-pit-mining methods - since labor productivity at open-pit mines is much higher than at underground operations (except in Alabama, where the ore mined by open-pit methods is unusually lean and requires much beneficiation at the mines). Modern open-pit mining, which followed the discovery of large deposits of soft, high-grade ore near the surface, is comparatively simple. The earth covering the ore body is first stripped off a large area by power shovels, and the ore is excavated in successive benches as the pit grows larger and deeper. The ore generally requires but little loosening and is usually loaded directly into railroad cars and pulled out of the pits by powerful steam or electric locomotives, although some of the more recent developments include truck, tractor, and belt-conveyor haulage.[1]

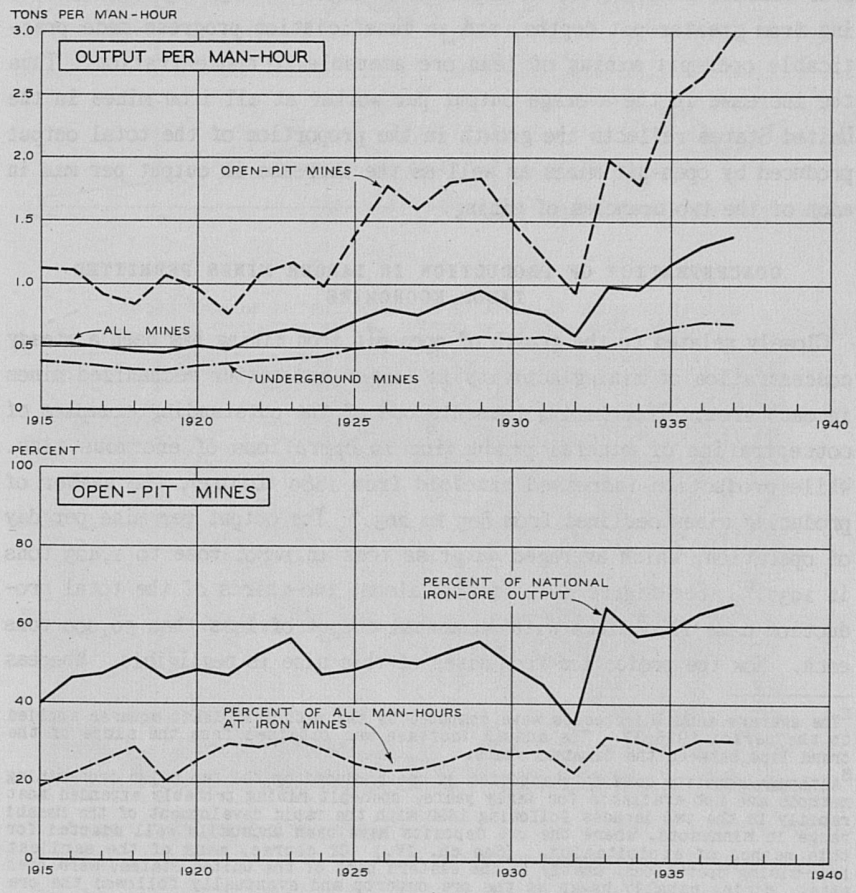
The average output of merchantable ore per man-hour at open-pit operations during the 23 years from 1915 to 1937 for which data are available was 1.32 gross tons as compared with 0.44 gross ton for underground

*By N. Yaworski and O. E. Kiessling.

[1]For a more detailed statement of the labor-saving advantages of open-pit mining and its more rapid growth as compared to underground methods, see ch. IV.

mines. (See figure 4.) Moreover, output per man at open-pit mines increased more rapidly than at underground mines. During the 23-year period the average annual increase at open-pit operations was 0.071 gross ton per man-hour as compared with 0.016 gross ton in underground

Figure 4.- OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES AND RELATIVE IMPORTANCE OF OPEN-PIT PRODUCTION AND MAN-HOURS, 1915-37



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The open-pit method of mining requires much less labor than mining by underground methods. In the 23-year period 1915-37, for which data are available, output per man at open-pit mines was three times as high as at underground mines and increased more rapidly. About half of the national output of iron ore during this period was produced by open-pit mines; but, owing to their low unit labor requirements, they contributed only about one-fourth of the total man-hours of employment opportunity.

In 1915 about 40 percent of the national output was produced by open-pit mines; by 1937 this proportion had increased to 66 percent. Thus the increase in the average output per worker for all iron mines in the United States reflects the growth in the proportion of the total output produced by open-pit mines as well as the increase in output per man for each of the two branches of mining. (See table A-6 for data.)

mining.[2] About half of the national output of iron ore during the past quarter-century was produced in open-pit mines, but, owing to their high output per man-hour, they required only about one-fourth of the total man-hours. The percentage of the total output produced by open-pit mines increased from 40 percent in 1915 to 66 in 1937, despite the gradual depletion of the most accessible ore deposits.[3] Open-pit mining continued to expand as economical methods were developed for removing ever thicker overburdens, as improved haulage techniques permitted mining from greater pit depths, and as beneficiation progress made practicable open-pit mining of lean ore amenable to concentration. Thus the increase in the average output per worker at all iron mines in the United States reflects the growth in the proportion of the total output produced by open-pit mines as well as the increase in output per man in each of the two branches of mining.

CONCENTRATION OF PRODUCTION IN LARGER MINES PERMITTED LABOR ECONOMIES

Closely related to the growth of open-pit iron mining has been a steady concentration of mining activity in larger and better mechanized mines in each area. Iron mining presents one of the outstanding examples of concentration of mineral production in operations of enormous size. While production increased ninefold from 1880 to 1937, the number of producing mines declined from 805 to 205.[4] The output per mine per day of operation, which averaged 34 gross tons in 1880, rose to 1,423 tons in 1937.[5] (See figure 5.) In 1880 almost two-thirds of the total production came from mines with an annual output of less than 50,000 tons each. Now the production from mines of this size is negligible. Whereas

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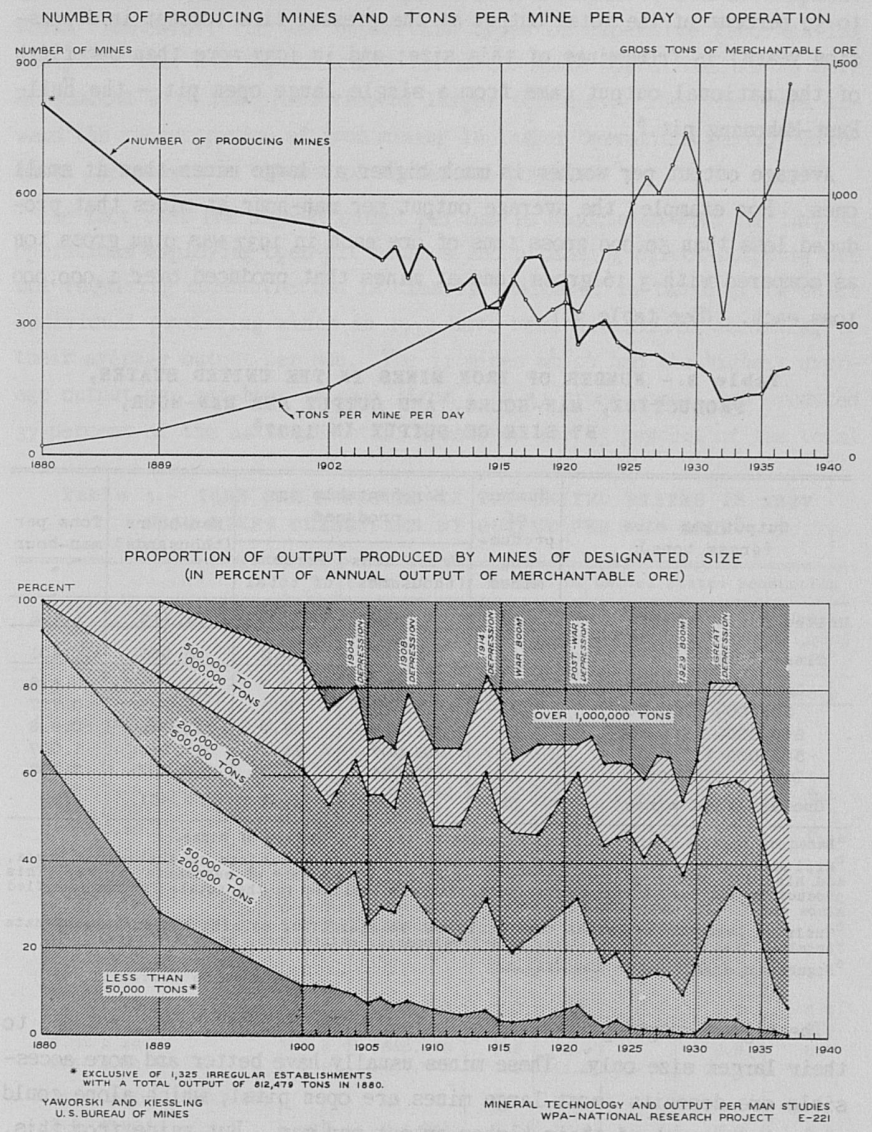
[2]The average annual increases were computed by the method of least squares applied to the period 1915-37. The annual increase was obtained from the slope of the trend line between the terminal years.

[3]Although complete data on quantities of ore produced by the two major iron-mining methods are not available for early years, open-pit mining probably expanded most rapidly in the two decades following 1892 with the rapid development of the Mesabi range in Minnesota, where the ore deposits have been unusually well adapted for this method of exploitation. (See ch. IV.) Of course, many of the earliest iron-mining operations, mostly in the eastern part of the United States, were open pits. Mining usually began at the ore outcrop and eventually followed the ore underground.

[4]Data are from table A-11. The problem of counting mines is a difficult one. With continued mining, two or more adjacent properties often blend into what may, to all appearances, be regarded as one continuous operation, the dividing property lines being distinguishable only to engineers. When such an operation is worked as a unit by one company, it should be properly counted as one mine; but sometimes it is operated by two or more companies, each with its own equipment. Care is taken to avoid trespassing on adjoining mineral property. Thus a count of mines is at best an approximation and depends on how a mine is defined. For the purpose of measuring the trend in size of mines over a number of years, it was deemed advisable to follow a consistent method of counting mines even though additional refinements would have been possible for certain years.

[5]Although the trend of output per mine per day of operation was generally upward, considerable declines were registered in depression years and unusual increases in years of high demand for ore. (See fig. 5.)

Figure 5.- THE TREND TOWARD CONCENTRATION OF IRON-ORE PRODUCTION IN LARGER MINES, 1880–1937



* EXCLUSIVE OF 1,325 IRREGULAR ESTABLISHMENTS WITH A TOTAL OUTPUT OF 812,479 TONS IN 1880.

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The iron-mining industry presents one of the most outstanding examples of the concentration of mineral production - not only within a small geographic area but also in a small number of mines of enormous size. The number of producing mines in 1937 was about one-fourth the number in 1880; over this period, however, production increased ninefold. The output per mine per day of operation, which averaged 34 gross tons in 1880, rose to 1,423 tons in 1937. In 1880 almost two-thirds of the total production came from mines with an annual output of less than 50,000 tons each. Now the production from mines of this size is almost negligible. On the other hand, whereas in 1880 not a single mine produced more than 1,000,000 tons, from 40 to 50 percent of the total output at the present time (except in depression years) is from mines of this size. In 1937 more than one-fifth of the national output came from a single large excavation. (See table A-11 for data.)

in 1880 not a single mine produced more than 1,000,000 tons, from 40 to 50 percent of the total output at the present time (except in depression years) is from mines of this size; and in 1937 more than one-fifth of the national output came from a single large open pit - the Hull-Rust-Mahoning pit.[6]

Average output per worker is much higher at large mines than at small ones. For example, the average output per man-hour at mines that produced less than 50,000 gross tons of ore each in 1937 was 0.44 gross ton as compared with 3.16 gross tons at mines that produced over 1,000,000 tons each. (See table 3.)

Table 3.- NUMBER OF IRON MINES IN THE UNITED STATES, PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR, BY SIZE OF OUTPUT IN 1937[a]

Output per mine (gross tons)	Number of producing mines	Merchantable ore produced		Man-hours (thousands)	Tons per man-hour
		Gross tons (thousands)	Percent of total		
United States total	209[b]	72,094	100.0	51,416	1.402
Classified mines, total	154	64,408	89.3	45,965	1.401
Less than 50,000	52	523	0.7	1,193	0.438
50,000- 200,000	31	3,855	5.3	5,375	0.717
200,000- 500,000	34	11,460	15.9	12,546	0.913
500,000-1,000,000	26	18,507	25.7	17,343	1.067
Over 1,000,000	11	30,064	41.7	9,507	3.162
Unclassified mines[c]	55[b]	7,685	10.7	5,451	(d)

[a] Based on reports of iron-mining companies to the U. S. Bureau of Mines.

[b] Excludes an undetermined number of small open-pit operations in Alabama, Georgia, and Missouri, which produced a total of 49,611 gross tons of merchantable ore. This production and the corresponding employment are included in the totals for unclassified mines and for the United States.

[c] Includes data for all mines that could not be classified by size and employment data for mines that were idle or doing only development, maintenance, or repair work.

[d] Figure not significant. See ftn. c.

The higher output per worker at bigger mines is, of course, not due to their larger size only. These mines usually have better and more accessible ore deposits (most large mines are open pits), which alone could account for much of their higher output per man. But aside from this, the trend toward concentration of iron-ore production in larger operations has permitted labor economies that could not have been achieved otherwise. It has made feasible carefully planned operation with highly paid and highly skilled technicians and engineers,[7] and it has eliminated

[6] Though one large continuous excavation, this pit includes several mines operated by different companies - namely, Hull-Rust, Mahoning, Burt, Sellers, Webb, and the Susquehanna. All together, these mines produced 17 million gross tons of merchantable ore in 1937.

Footnote 7 appears on following page.

or avoided some duplication of personnel, equipment, and development work. Moreover, the use of certain types of expensive labor-saving equipment that was impracticable for small-scale operations became more economical with the production of larger tonnages. Thus the trend toward the concentration of iron mining in larger operations partly influenced the growth in the use of mechanical power.

The fact that the highest output per man is associated with the largest operations employing open-pit methods and producing direct-shipping ore not requiring concentration is clearly indicated in table 4, in which individual producing mines in 1937 have been classified according to their average output per man. The 11 mines which had the highest average output per man-hour in 1937 (from 5 to 11 gross tons), and produced 37 percent of the national total, accounted for 55 percent of the total

Table 4.- IRON ORE PRODUCED IN THE UNITED STATES IN 1937 FROM MINES CLASSIFIED BY OUTPUT PER MAN-HOUR[a]

Output per man-hour (gross tons)	Mines		Percent of United States production				
	Number	Output per mine	Total	From open pits	From underground	Concentrated ore	Direct-shipping ore[b]
United States total	209	344,945	100.0	100.0	100.0	100.0	100.0
(Class interval of 0.10)							
0 - 0.09	2	366	(c)	-	(c)	(c)	-
0.1- 0.19	17	797	(c)	(c)	(c)	-	(c)
0.2- 0.29	32	44,043	2.0	0.4	4.9	11.3	0.2
0.3- 0.39	16	45,221	1.0	0.3	2.4	2.4	0.7
0.4- 0.49	10	30,830	0.4	0.6	(c)	2.4	0.1
0.5- 0.59	11	258,660	3.9	0.1	11.4	0.9	4.5
0.6- 0.69	17	269,371	6.4	0.2	18.1	0.9	7.4
0.7- 0.79	8	389,443	4.3	0.2	12.2	-	5.1
0.8- 0.89	9	380,176	4.7	0.1	13.7	0.5	5.8
0.9- 0.99	14	389,239	7.6	1.0	20.3	4.6	8.1
(Class interval of 0.50)							
1.0- 1.49	15	277,282	5.8	4.9	7.4	5.0	5.9
1.5- 1.99	25	275,048	9.5	10.2	8.4	24.7	6.7
2.0- 2.49	4	346,268	1.9	2.9	-	8.5	0.7
2.5- 2.99	8	650,772	7.2	11.0	-	20.9	4.6
(Class interval of 2.00)							
3.0- 4.99	10	611,834	8.5	12.9	-	17.9	6.7
5.0- 6.99	6	992,795	8.3	11.9	1.2[d]	-	9.8
7.0- 8.99	3	5,109,661	21.3	32.3	-	-	25.3
9.0-10.99	2	2,598,120	7.2	11.0	-	-	8.6

[a] Data are from table A-7.

[b] Ore that did not require concentration before shipment and includes ore that was simply crushed or screened.

[c] Less than 0.1 percent.

[d] Represents production from the underground portion of a mine that employed a combination of open-pit and underground-mining methods.

[7] The proportion of salaried employees - including superintendents, foremen, technical employees, office employees, etc. - has increased steadily from 4 percent of all employees in 1880 to 7.4 percent in 1929 and 8.4 percent in 1935. (See table 1.) In part, this increase represents more careful planning and supervision of workings and better recording and analysis of operating data by specially trained personnel.

output from open-pit mines and for 44 percent of all direct-shipping ore. Only 1.2 percent of all underground production came from these mines, and none of their output required concentration. These 11 mines produced an average of 2,400,000 gross tons of ore per mine as compared with an average of about 230,000 gross tons for all other mines.

TECHNOLOGICAL ADVANCES HAVE REDUCED LABOR REQUIREMENTS

Technological improvements, both the large, spectacular changes and the numerous alterations in details, have reduced labor requirements in iron mining - first, by the progressive substitution of mechanical power for manual labor, and second, by constant improvements in equipment whereby machine output was increased while the labor necessary to maintain and operate it was reduced. As iron-ore production expanded and operations were conducted on a bigger scale, machine capacities were enlarged not only by building larger and more powerful units but also by increasing their speed, mobility, and durability. This reduced delays or interruptions and increased the effective working time of men and machines.

Improved mining techniques have included not only the use of more mechanical power and larger, more efficient machinery but also the more skillful use of equipment and a more systematic ordering of work. Better management, more comprehensive and scientific planning, and more careful supervision have resulted in better coordination of functions and in better adaptation of techniques to the particular natural conditions encountered.

Gradual Adoption of Improved Techniques

Except for the general acceleration in the introduction of labor-saving techniques in the post-war period, new methods and equipment in the iron-mining industry as a whole were adopted gradually and influenced output per man accordingly. There are numerous economic and psychological resistances to the rapid and simultaneous adoption of new techniques even after they become known. Existent equipment may continue to be serviceable for a long time, and the expected savings in operating costs may not be sufficient to offset the high initial cost of new equipment. The older equipment may be well adapted to the plan and size of the mine, the management accustomed to and sure of its performance, and the workmen experienced in its use. Operating conditions at the mine where a prospective change is considered are seldom the same as those at the mine where a new technique has been first successfully applied; even though the advantages of a new practice have been amply

demonstrated, the possible savings that may be realized under different operating conditions are not entirely certain. For this reason, the mine manager adopts innovations cautiously, often preferring first to try a few new units experimentally or to modify and improve existing equipment. The scale of operations or the anticipated life of the mine may not warrant large outlays for new machinery, even though considerable savings in operating expense could be realized. To the uncertainty of possible savings must be added the difficulty in estimating future demand and the prospect of mine idleness. Depreciation of mechanical equipment in periods of inactivity is costly. On the other hand, labor may be laid off and labor cost almost eliminated during periods of shutdown; hence if the outlook for ore demand is poor, the operator may prefer to postpone the purchase of new machinery.

For such reasons the adoption of improvements in the art of mining was not uniform, and at any one time wide differences could be found in the extent of the application of labor-saving techniques. Moreover, unlike manufacturing, mining is characterized by wide variations in natural conditions encountered, a factor which greatly influences mining efficiency. In addition to these dissimilarities in operating conditions, differences in the size of operations, in the proportion of productive capacities utilized, and in the amount of development work bring about wide differences in output per man at individual mines.

Under these circumstances the precise influence of technological changes on output per man in the iron-mining industry is not amenable to statistical measurement, and judgment regarding their influence must be on the basis of qualitative analysis.[8] An essential feature of technological progress, however, is the increased use of mechanical power in the place of human labor, and this development is easily demonstrated by the use of quantitative data.

Progress in the Use of Power Equipment

The increasing importance of power machinery in the iron-mining industry over the past half-century is roughly indicated by the rapid rise both of aggregate horsepower of mechanical equipment and of horsepower

[8] Although for some mines fragmentary statistical data are available to measure the effects of the introduction of individual technical changes on worker output in the performance of specific tasks, the effects of these changes on over-all man-hour output at a given mine or group of mines are obscured by the more or less simultaneous introduction of other changes and possible alterations in other operating conditions. Moreover, the various tasks performed in the course of mining are more or less interrelated, and increased productivity in one is reflected directly or indirectly in the performance of other functions. Individual mining operations encounter many different natural and other conditions, and the adoption of a specific method does not always have the same effect at other mines. Furthermore, although the approximate dates of the first use of most techniques are pretty well known, there is a scarcity of quantitative data as to the rate and extent of their adoption.

per wage earner.[9] (See figure 6.) The horsepower of equipment per wage earner increased from 0.9 in 1880 to 6.6 in 1909 and to 16.2 in 1929. The growth in the use of power equipment was particularly rapid prior to 1909; and although the aggregate horsepower of all power equipment increased less rapidly after 1909, the available power was used more efficiently. The total horsepower of steam-driven equipment diminished after 1909, but this decline was more than offset by an extraordinary advance in the use of electric motors.

The upward trend of horsepower per wage earner, despite an increase in the proportion of total output from open-pit mines, which use relatively less power, is partly indicative of a substitution of mechanical power for human and animal energy. Part of the increase shown in average output per worker arose from the substitution of mechanical energy for manpower. The drop in the utilization of animal power is even more spectacular. In 1880 the census reported 3,993 horses and mules in use at iron mines. By 1889 the number reported was 2,796, representing a reduction of almost a third in the space of 9 years, during which iron-ore production doubled. Reports of iron-mining companies to the United States Bureau of Mines indicated that from 150 to 200 animals were in use at iron mines in 1936 and 1937 - virtually all in the State of Alabama.

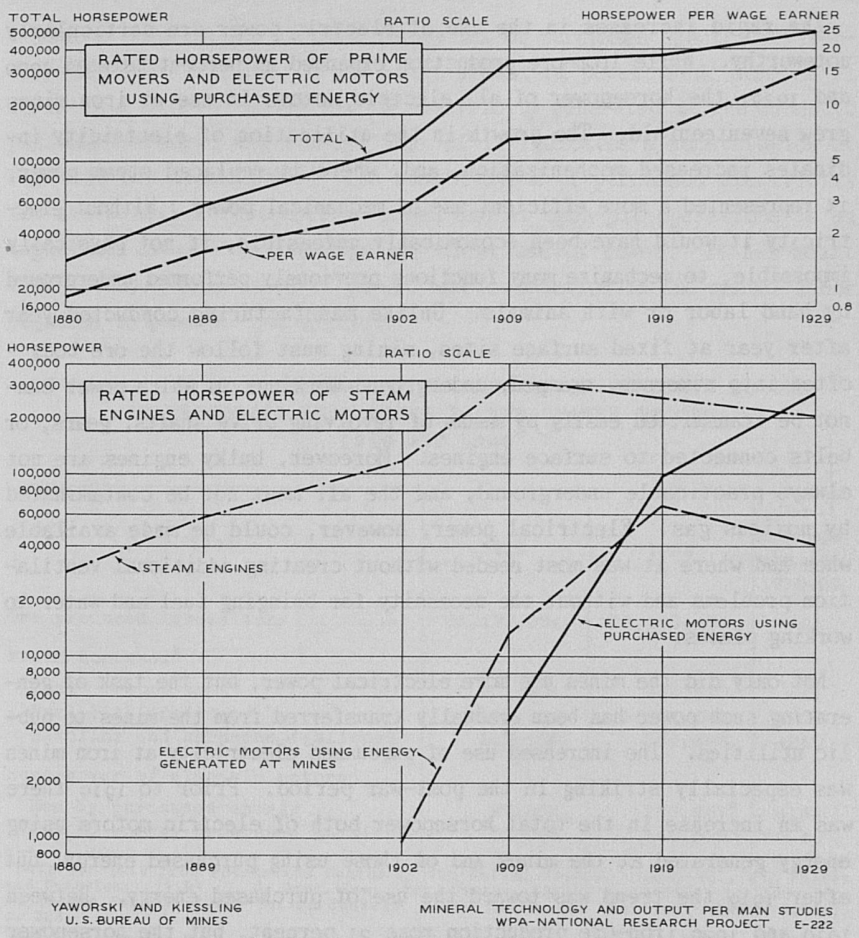
Mechanical power was employed partly to overcome natural difficulties. Greater depth of operations required speedier hoisting in longer shafts. The depletion of the more accessible ore bodies near shafts required more extensive development of underground operations, longer haulage distances, more ventilation, and more water pumping. The gradual depletion of the highest-grade deposits necessitated the beneficiation of lower-grade ores. Thus the horsepower per wage earner in 1929 was highest at iron mines in such States as New York, New Jersey, Pennsylvania, Michigan, and Wisconsin,[10] where the mines are older and mostly underground. In New York and New Jersey, moreover, the crude ore mined must

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[9] The figures on horsepower represent the rated capacity of engines, motors, etc., not the amount of power in actual use, and cover both stationary and mobile equipment. The latter embraces power shovels, locomotives, trucks, scraper loaders, churn drills, and other power machinery moved from place to place in the course of operations, as contrasted with fixed or stationary installations, such as central power plants, hoisting, air-compressing, ventilating, pumping, crushing, screening, washing, and other equipment. The data for aggregate horsepower do not cover the rating of electric motors using energy generated at the mines, nor of the electric generators supplying them with current; these are operated by prime movers reported by the same enterprise, and their inclusion would obviously result in duplication. (See summary of data in table A-12.)

[10] See table A-12. The mines in these States also consume the largest amount of electricity per ton of ore produced. In 1929 iron mines and beneficiating plants in New York, New Jersey, and Pennsylvania used an average of 32.9 kilowatt-hours per ton of merchantable ore produced; in Michigan, 12.2; and in Wisconsin, 8.5, as compared with 2.0 kilowatt-hours for Minnesota and 6.4 for the whole industry. (See table A-14.)

Figure 6.- GROWTH IN THE USE OF POWER EQUIPMENT AT PRODUCING IRON MINES IN THE UNITED STATES, 1880-1929



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The trend toward increased mechanization of iron mines in the past half-century is indicated by the growth in the rated horsepower of mechanical equipment per wage earner, which increased from 0.9 in 1880 to 6.6 in 1909 and to 16.2 in 1929. Since 1909 the use of equipment operated by steam power has declined, while the use of the more efficient electric motors, especially those driven by purchased energy, has advanced sharply.

The increase in horsepower per wage earner, despite an increase in the proportion of total output from open-pit mines, which require less power, represents a substitution of mechanical force for human and animal energy, and it has served not only to offset mounting physical difficulties but also to register net gains in output per man. (See table A-12 for data.)

usually be concentrated before shipment. However, despite the gradual but definitely perceptible depletion of the best and most accessible ore deposits, unit labor requirements have declined in all important producing areas. Mine operators have successfully applied new techniques and better designed and more powerful machines,[11] not only to overcome

Footnote 11 appears on following page.

mounting physical difficulties but also to register net gains in output per hour of human effort expended.

The rapid increases in the use of electric power are particularly noteworthy. While iron-ore production expanded 42 percent between 1909 and 1929, the horsepower of all electric motors in use at iron mines grew seventeenfold. The growth in the utilization of electricity indicates increased mechanization, and, where it replaced steam power, it represented a more efficient use of mechanical power. 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. Unlike manufacturing conducted year after year at fixed surface sites, mining must follow the ore body - often into numerous, cramped, underground workings to which power cannot be transmitted easily by means of revolving drive shafts, gears, or belts connected to surface engines. Moreover, bulky engines are not always practicable underground, and the air must not be contaminated by noxious gas. Electrical power, however, could be made available when and where it was most needed without creating additional ventilation problems and without the necessity for bringing fuel and water to working places.

Not only did the mines use more electrical power, but the task of generating such power has been gradually transferred from the mines to public utilities. The increased use of purchased electricity at iron mines was especially striking in the post-war period. Prior to 1919 there was an increase in the total horsepower both of electric motors using energy generated at the mines and of those using purchased energy; but after 1919 the trend was toward the use of purchased energy. Between 1919 and 1929 iron-ore production rose 21 percent, but the horsepower of electric motors run by purchased energy rose 184 percent, while the horsepower of motors driven by electricity generated at the mines declined 40 percent and the consumption of coal decreased 41 percent. (See table 5.) The actual quantity of electricity sold by electric utilities to iron-mining companies operating in the Lake Superior District, as reported to the United States Bureau of Mines, rose from 138,400,000 kilowatt-hours in 1923 to 231,960,000 kilowatt-hours in 1937, an increase of 68 percent, whereas the total production of iron ore in the

[11] The average horsepower rating per steam engine, for example, increased from 30 in 1880 to 53 in 1889, to 92 in 1909, and to 203 in 1929. Centralization in power generation and reduction in the number of separate units to be maintained and operated in relation to the quantity of ore produced reduced the amount of labor directly engaged in supplying a unit of power. (Data were derived from sources indicated in table A-12.)

Lake Superior District during the same interval of time rose only 3.5 percent. (See figure 7 and table A-13.)

Some of this growth in the consumption of purchased electricity represents a net increase in the total amount of power used; some of it reflects a shift from the use of electricity generated at the mines to purchased energy; and a large part of it indicates a substitution of electric for steam power. The substitution of purchased electricity for steam both at underground mines and at open-pit operations is an important advance in the more efficient use of power. It has meant fewer delays, less waste of power, and a reduction in the manual labor required to generate and apply it.

Table 5.- FUEL CONSUMED AND HORSEPOWER OF ELECTRIC MOTORS AT PRODUCING IRON MINES IN THE UNITED STATES, 1919 AND 1929[a]

Item	1919	1929	Percentage change, 1919-29
Ore produced (gross tons)	61,173,254	73,963,485	+21
Fuels consumed[b]			
Coal[c] (short tons)	1,601,805	949,510	-41
Fuel oil[d] (gallons)	158,634	1,201,942	+658
Gasoline and kerosene (gallons)	149,100	506,898	+240
Horsepower of electric motors			
Run by purchased energy	97,382	276,667[e]	+184
Run by energy generated at mines	67,595	40,688[f]	-40

[a] Data for 1919 from *Fourteenth Census of the United States: 1920*, Vol. XI, "Mines and Quarries: 1919" (U. S. Dept. Com., Bur. Census, 1922), pp. 349-51; for 1929 from *Fifteenth Census of the United States: 1930*, "Mines and Quarries: 1929" (1933), p. 326.

[b] Excludes very small quantities of manufactured gas and wood.

[c] Mainly bituminous coal but includes small quantities of anthracite and coke.

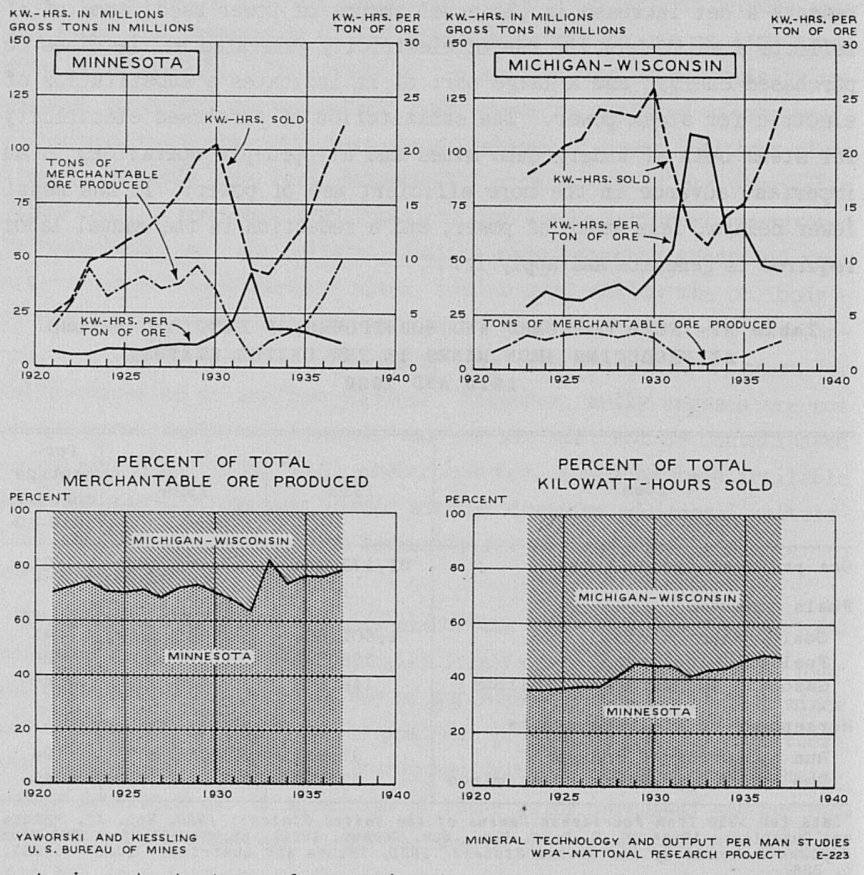
[d] Excludes fuel oil consumed in Pennsylvania.

[e] These motors consumed 375,636,018 kilowatt-hours of electricity, which represent about 317,000 short tons of coal or coal equivalent of other fuels when computed by assuming the same average consumption of fuel (1.69 lb.) per kilowatt-hour as experienced in 1929 by central electric-power stations in the United States using steam to generate electricity for sale. (See also tables A-13 and A-14.)

[f] These motors consumed 99,735,238 kilowatt-hours of electricity, which represent about 84,000 short tons of coal or coal equivalent of other fuels when computed as described above. (See also table A-14.)

In recent years steam engines and electric motors have been augmented by internal-combustion engines, a development that was clearly reflected in the rising consumption of fuel oil and gasoline in the post-war decade. (See table 5.) Such engines have been used with notable success at open-pit operations for truck or tractor haulage, for scraping, and for power-shovel loading, and they promise to play an even more important role in the future.

Figure 7.- ELECTRICITY SOLD TO IRON-MINING COMPANIES, TOTAL ORE PRODUCED, AND KILOWATT-HOURS PURCHASED PER TON PRODUCED IN THE LAKE SUPERIOR DISTRICT, 1921-37



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An important phase of mechanization progress at iron mines in the post-war period was the growth in the use of electricity, especially purchased energy, which by 1929 constituted 95 and 67 percent of the total electricity consumed at iron mines in Minnesota and Michigan-Wisconsin respectively. Notwithstanding the fact that a smaller proportion of the electricity consumed in Michigan and Wisconsin was purchased and that these States accounted for less than one-third of the iron ore produced in the Nation, they purchased over half of the total kilowatt-hours sold to iron-mining companies in the Lake Superior District. This is because most of the mines in Michigan and Wisconsin are underground and require more power per unit of product than in Minnesota where the output is mainly from open-pit mines.

The number of kilowatt-hours purchased by iron-mining companies per ton of merchantable iron ore produced in 1937 increased substantially over 1923. In both of these years iron-ore production was unusually high. During 1931-36, however, the large rise in the consumption of purchased electricity per ton of ore was due to purely temporary influences associated with the depression. Iron mines had greatly reduced their production schedules, and a large number of them were closed down entirely. Much power had to be consumed, nevertheless, to maintain the mines in good working condition, especially in pumping water to keep them dry. (See table A-13 for data.)

Technology Has Increased Output per Man Despite Depletion

Although technological progress has increased average output per worker at most iron mines, at others it has acted to offset a tendency for productivity to decline because of mounting physical difficulties. Improved methods of drilling, loading, haulage, and beneficiation, for instance, have permitted the continued expansion of open-pit mining with its low labor requirements, despite thicker overburdens, deeper pits, leaner ore, and, more recently, the trend toward exploitation of the smaller ore deposits near the surface.

Beneficiation progress has been of special importance in overcoming the effect of a decline in the available quantities of high-grade, direct-shipping ore. A gradually increasing proportion of the ore produced has had to be improved, or beneficiated, before shipment. The proportion of beneficiated ore shipped from Minnesota, which produces the bulk of it, increased from 0.6 percent of the State total in 1906 to 41 percent in 1937.[12] However, a large part of this included ore that was processed simply by crushing or screening, which involves relatively little additional labor. The proportion of total shipments from Minnesota constituting concentrated ore, from which some waste or moisture was removed to increase the proportion of metallic iron contained, increased from 1.0 percent in 1909 to a peak of 25.1 percent in 1935 and declined to 19.5 percent in 1937.[13] For the entire United States the ratio of concentrates to total merchantable ore produced increased from 1.7 percent in 1909 to a peak of 18.0 percent in 1935 and declined to 16.0 percent in 1937, although the actual quantity of concentrates produced in 1937 (11,500,000 gross tons) exceeded all previous records. (See figure 8 and table A-8.)

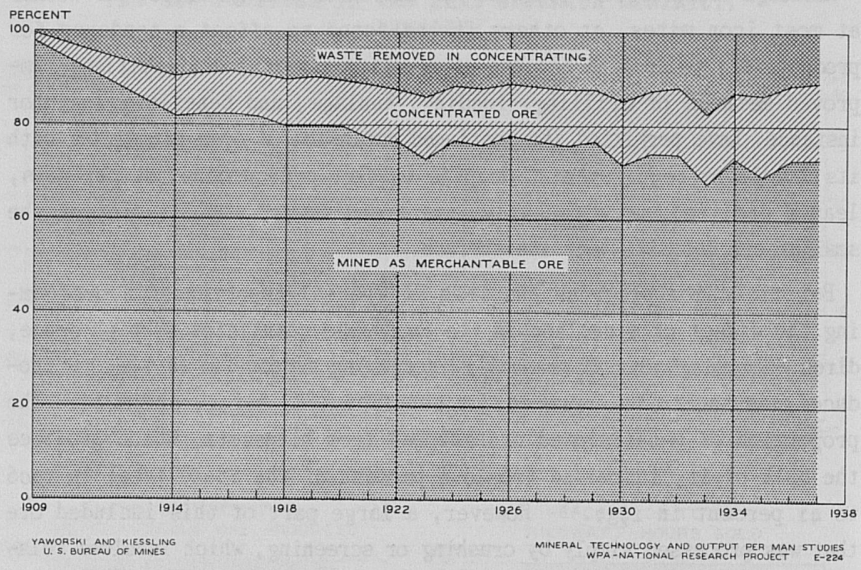
The necessity of handling and removing waste material from crude ore which would not otherwise be merchantable requires much additional labor and cuts down considerably the output per man. For example, during the 15 years 1923-37 the average output of merchantable ore per man-hour at open-pit mines in Minnesota which did not have to concentrate their ore was 2.57 gross tons as compared to 1.35 gross tons for open-pit mines, all or part of whose crude ore required concentration.[14] The latter

[12] Data are from John J. Craig, *Mining Directory of Minnesota, 1938*, Vol. XLI, No. 30 (Univ. of Minn., School of Mines Expt. Sta., May 1, 1938), p. 204.

[13] Although the shipments of concentrates in 1937 represented a smaller proportion of total ore shipments from Minnesota than in 1935, the actual amount of concentrates shipped in 1937 was 9,554,670 gross tons as compared to 5,154,469 gross tons in 1935. The amount of concentrates shipped from Minnesota in 1937 exceeded all previous records; yet, owing to limited concentrating-plant capacity, it did not expand so rapidly as direct-shipping ore.

[14] See table A-9. Data exclude mines which used a combination of open-pit and underground-mining methods; the open-pit output of such mines in Minnesota amounted to 12 percent of the total State production from open pits during 1923-37. [*Con.*]

Figure 8.- GROWTH OF CONCENTRATION OF CRUDE ORE AT IRON MINES IN THE UNITED STATES, 1909-37



A gradually increasing proportion of the iron ore mined in the United States is too lean to be of merchantable grade and must be concentrated at the mines before being shipped to smelters. The beneficiation progress that has made this possible has not only augmented the available ore reserves but, by increasing the quantity of ore available for open-pit mining, has also reduced mining labor requirements. (See table A-8 for data.)

produced 72 percent of the total output of concentrated iron ore in the United States during 1923-37.[15]

Although the output of 1.35 gross tons per man-hour at concentrating open-pit mines during 1923-37 was not much more than half the man-hour output at open pits producing direct-shipping ore only, it was twice as high as the man-hour output (0.69 gross ton during 1923-37) at underground mines producing direct-shipping ore.[16] Despite additional labor required both to mine a larger quantity of the leaner crude ore and to concentrate it, the total labor requirements at open-pit mines, even with beneficiation, were much lower than at nonbeneficiating underground mines. Thus, by increasing the amount of ore available for open-pit

[14] [*Con.*] Of course, the difference in output per man at concentrating and nonconcentrating mines is not entirely due to concentration. Some differences may have been due to variations in physical conditions encountered and techniques employed. Moreover, the ratio of concentrated ore to total output at concentrating mines has fluctuated, for example, from a low of 71 percent in 1926 to a high of 96 percent in 1934; the ratio of tons per man-hour at nonconcentrating mines to that at concentrating mines has varied also - from 2.7 in 1926 to 2.0 in 1934.

[15] See table A-10 for a comparison of output per man-hour at all concentrating iron mines with that of all nonconcentrating mines in 1936-37, classified by State and mining method.

[16] See table A-6. The amount of ore produced in Minnesota from underground mines that is concentrated is negligible.

mining, beneficiation progress in Minnesota has been an important factor in raising the average output per worker.

The bulk of the concentrates in Minnesota were produced by simple washing methods. The lean ores amenable to this method are being rapidly exhausted, however, and the vast deposits of other lean ores which remain unexploited will require more complicated methods of treatment.[17]

Perhaps the most serious obstacle that technology has to overcome is increasing depth of mining. The maximum vertical depth of underground iron mines in Michigan and Wisconsin in the past score of years has increased almost 600 feet, from an average of 1,240 to 1,820 feet; and the average depth of underground mines in Minnesota in 1937 (700 feet) was about 330 feet deeper than in 1916.[18] (See table 6.) The depth of underground mines in other producing areas and open-pit mines has probably increased similarly.

Table 6.- MAXIMUM VERTICAL DEPTH OF UNDERGROUND IRON MINES IN THE LAKE SUPERIOR DISTRICT, 1916 AND 1937[a]

State and range	1916			1937		
	Number of mines	Ore shipments (millions of gross tons)	Weighted average maximum vertical depth[b] (feet)	Number of mines	Ore shipments (millions of gross tons)	Weighted average maximum vertical depth[b] (feet)
Lake Superior District	180	33.5[c]	854	45	15.5[d]	1,511
Michigan and Wisconsin	98	18.6	1,243	31	11.1	1,825
Gogebic	22	7.0	1,792	10	4.7	2,531
Marquette	34	5.8	1,030	11	4.7	1,440
Menominee	42	5.8	786	10	1.7	968
Minnesota	82	14.9	370	14	4.4	706
Cuyuna	11	1.0	281	-	-	-
Mesabi	63	11.9	251	10[e]	2.9	357
Vermilion	8	2.0	1,141	4	1.5	1,400

[a] Data for 1916 from *The Iron Ores of Lake Superior* (3d ed.; Cleveland, Ohio: Crowell & Murray, 1917), pp. 115-311; for 1937, data on depths from reports of iron-mining companies to the U. S. Bureau of Mines, and data on shipments from *Lake Superior Iron Ores: 1938* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), pp. 100-277.

[b] In computing the average, the depth of each mine was weighted by the amount of ore shipped from that mine.

[c] Represents about 95 percent of the total shipments from underground mines.

[d] Represents about 89 percent of the total shipments from underground mines.

[e] Includes one mine on the Cuyuna range.

[17] See ch. VI for a statement of the possible effect this may have on future labor requirements.

[18] These averages (weighted by mine shipments) are based on the largest number of mines for which depth data were available in 1916 and 1937, and each average does not represent the same mines in each district considered. A similar analysis of the depths of 17 identical underground mines in Michigan and Wisconsin indicated an increase in the maximum vertical depth from 1,625 feet in 1916 to 1,893 feet in 1937; and the depth of 6 identical mines in Minnesota increased from 763 feet to 981 feet during the same period. (See table A-21.)

Increasing depth of underground workings adds to the difficulty of mining by imposing many additional problems. With greater depth a longer time is required for the hoisting operation; the weight of the hoisting cable increases, thereby necessitating a reduction in the pay load. Larger, speedier, and more powerful hoisting equipment becomes indispensable. The sinking of new shafts becomes less practicable, and with continued horizontal expansion of mine workings, longer haulage distances create the need for more efficient haulage methods and equipment, as well as a better coordination of all transportation functions. The greater weight of overlying rock and other material imposes additional strains that may add to the mining hazard and require additional artificial supports. Drainage water must be lifted a greater distance, requiring more powerful pumps. Deeper mines may also require the installation of special ventilation equipment in addition to that usually employed.

Increasing depth of open pits has also created technical problems, especially in removing material from the pit. Where the same haulage grades were retained despite greater depth, it was necessary to introduce additional track "switch-backs" or "spirals." This increased the distance over which trains traveled and either introduced haulage delays or multiplied the number of necessary trains and their crews. Additional switch-backs increased the number of train stops; added spirals sometimes necessitated sharper curves; and the addition of either one added to the quantity of ore tied up in benches. Additional switch-backs or spirals sometimes increased the amount of development work, as for cutting new approaches. Some pits were able to reach deeper ore by increasing haulage grades, if they were not already excessive; but this has either resulted in the reduction of the size of trains or has necessitated the use of more powerful locomotives. In some deep open pits with limited horizontal dimensions, it has been necessary to abandon the customary methods of haulage altogether and to resort to hoisting or to the use of trucks or belt conveyors.

To the difficulties resulting from adverse natural mining conditions has been added the problem of meeting the more exacting requirements of smelters. These demanded ore containing not only the proper percentage of iron but also no more than the prescribed amounts of phosphorus, sulphur, and silica. Increasing emphasis on the chemical content of the ore excavated made it more difficult for operations to be more continuous and efficient from the standpoint of output per man, and mining necessarily became more selective. In open-pit mines, for example, power shovels cannot always continue to load ore from the same ore bank

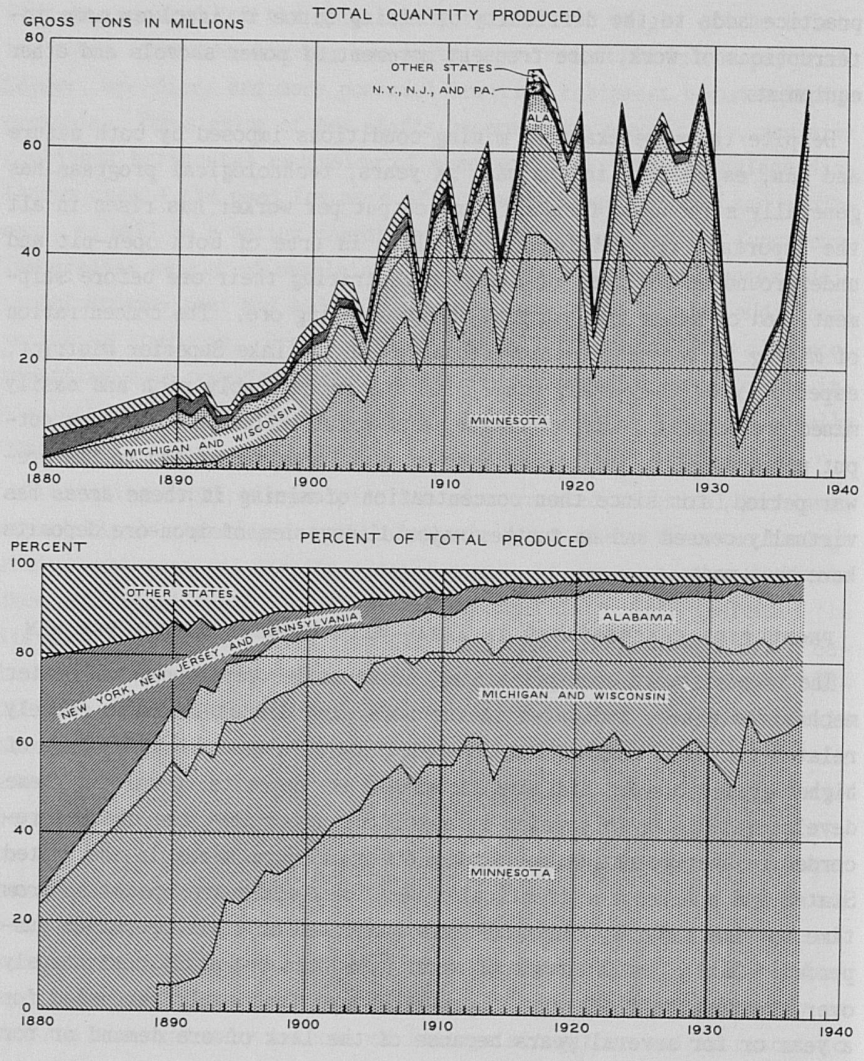
but must mine those portions of the ore body which will yield (perhaps with further mixture) a product of requisite merchantable grade. This practice adds to the difficulty of mining since it involves more interruptions of work, more frequent movement of power shovels and other equipment.

Despite the more exacting mining conditions imposed by both nature and man, especially in the past 25 years, technological progress has generally surmounted them all, and output per worker has risen in all the important iron-mining areas. This is true of both open-pit and underground operations, of mines concentrating their ore before shipment, and of mines that produce direct-shipping ore. The concentration of mining in the newly discovered areas of the Lake Superior District, especially on the Mesabi range with its incomparably rich and easily mined ore deposits, was, of course, a powerful influence in raising output per man. This influence, however, was largely confined to the prewar period, for since then concentration of mining in these areas has virtually ceased and no further major discoveries of iron-ore deposits have been made.

PRODUCTION CONCENTRATED IN AREAS WITH HIGHEST OUTPUT PER MAN

The trends toward open-pit mining, large-scale operations, and better mechanized mines, indicated in the foregoing discussion, are closely related to the concentration of production in areas which, because of higher grade, larger, and more accessible ore deposits, permitted these developments. At this point it should be noted that the changes recorded in average output per worker cover all iron mines in the United States and are not for identical mines. New mines are opened up from time to time and many older ones are abandoned or their operation suspended. Only a small number of mines have been operating continuously over the past half-century. Operations are frequently suspended for a year or for several years because of the lack of ore demand or for some other reason. Such variations are reflected in changes of the average output per worker. When a larger proportion of the output is produced by mines with higher labor productivities, the average for the United States rises; when a smaller proportion is produced by them, it tends to decline. Thus this average for the United States may go up or down, even though there may be no change in output per man at any of the component mines. A similar result follows a shift of production among component iron-mining areas; if the differences in output per man among them are wide, any change in the proportionate share of the total output will affect the average for the United States.

Figure 9.- MERCHANTABLE IRON ORE PRODUCED IN PRINCIPAL AREAS IN THE UNITED STATES, 1880-1937



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Iron-ore production was characterized by rapid growth before the World War and arrested growth afterwards. A large factor in the pre-war rise in production was the rapid expansion of Minnesota's output. Her relative share in the national output increased from 8 percent in 1892 to over 60 percent in 1912 and thereafter. On the other hand, the proportion produced by all the other States, except Alabama, has declined since 1889, and, with the additional exception of Michigan and Wisconsin, since 1880.

Although iron-ore production in the post-war period fluctuated violently, the relative shares of important areas have remained fairly stable. Since 1915 Minnesota has produced 61 percent of the national iron-ore output; Michigan-Wisconsin, 24 percent; Alabama, 10 percent; New York, New Jersey, and Pennsylvania, 3 percent; and the remaining States, 2 percent. (See table A-1 for data.)

An important factor in raising the average output per worker in the iron-mining industry as a whole between 1889 and 1915 (from 1.8 gross tons per man-shift to 4.7 gross tons) was the rapid development and exploitation of the iron mines of Minnesota. From 1892, when the first ore was taken from the famous Mesabi range, until 1912 Minnesota's share of the national output increased from 8 to 62 percent. (See figure 9.) As pointed out later, a relatively large proportion of the ore in Minnesota is easily mined on a large scale by open-pit methods. Furthermore, except for Michigan and Wisconsin, a smaller proportion of the ore mined in Minnesota than in other chief producing States requires beneficiation before shipment; hence the average output per worker in Minnesota is much higher than in other States.

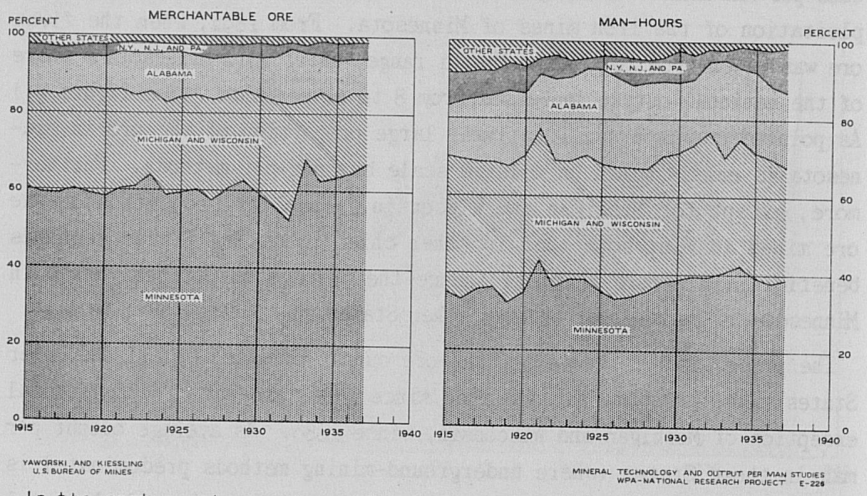
The proportion of the total iron-ore output produced by all the other States except Alabama has declined since 1889, and with the additional exception of Michigan and Wisconsin, since 1880. As average output per man in these States (where underground-mining methods predominate) is much lower than in Minnesota, the drop in the proportion of the total output produced by them - and a corresponding increase in the proportion produced by Minnesota - has served to raise the average output per worker for the country. The decline in the proportionate production by the Northeastern States - New York, New Jersey, and Pennsylvania - was especially pronounced. In 1880 these States produced about 53 percent of the national output; in the past quarter-century, however, their share has amounted to only 2 to 4 percent. Output per man in these States is relatively low, not only because the ore must be won mostly by underground-mining methods but also because additional labor is necessary to process the crude ore mined.

In the past quarter-century, however, the proportion of the total output contributed by the major producing States has remained fairly constant, although the total production of iron ore fluctuated widely. The concentration of iron-mining activity in the Lake Superior District ended about 1915, and this district now normally produces about 85 percent of the national output.[19]

In the 23-year period 1915-37, Minnesota produced 61 percent of the total iron-ore output of the country; but, because of low unit labor requirements, the State accounted for only 36 percent of the total man-hours worked in the industry. (See figure 10.) Iron mines in the remaining

[19] In periods of unusual demand for iron ore the proportionate production from Minnesota has increased at times because its open-pit mines were more capable of rapidly expanding their production than the underground mines of other States.

Figure 10.- PERCENT OF TOTAL MERCHANTABLE ORE PRODUCED AND MAN-HOURS WORKED IN PRINCIPAL AREAS IN THE UNITED STATES, 1915-37



In the past quarter-century Minnesota produced more than 60 percent of the Nation's iron-ore production with less than 40 percent of the total man-hours worked. Iron mines in the remaining States are relatively more important as employers of labor than as producers of iron ore. Unit labor requirements are lower in Minnesota, where most of the ore is mined by open-pit methods and is sufficiently high in iron content so that it can be shipped to smelters without concentration. (See table A-4 for data.)

States are relatively more important as employers of labor than as producers of ore.

Michigan and Wisconsin, second only to Minnesota in their level of output per man, contributed 24 percent of the national production of iron ore with 34 percent of the total man-hours of labor; Alabama produced 10 percent of the national output with 19 percent of the total man-hours; and New York, New Jersey, and Pennsylvania required 6 percent of the total man-hours to produce 3 percent of the total ore.

Output per Man Highest at Minnesota Mines

A comparison of the average levels of output per worker at iron mines in the important iron-mining areas shows the high level maintained by Minnesota since the beginning of iron mining in that State and especially after the development of the Mesabi range. The average output per man-shift in Minnesota since 1902 has been about 2.8 times as large as that of all other iron-ore-producing States combined. (See table 7 and figure 11.)

Available data for the post-war period enable comparison of the levels of output per man in the principal producing areas with two of the major influencing factors - namely, the proportions of the total output in

Table 7.- OUTPUT PER MAN-SHIFT AT IRON MINES IN MINNESOTA AND ALL OTHER STATES, 1899-1937[a]

Year	Output per man-shift		Ratio of output per man-shift in Minnesota to that in other States
	Minnesota	All other States	
1889	2.046	1.592	1.3
1902	6.112	2.225	2.7
1915	8.065	2.880	2.8
1920	7.972	2.936	2.7
1925	10.777	4.011	2.7
1930	11.435	4.761	2.4
1937	19.891	5.975	3.3
Average, 1915-37	10.021	3.636	2.8

[a]Data from table A-4.

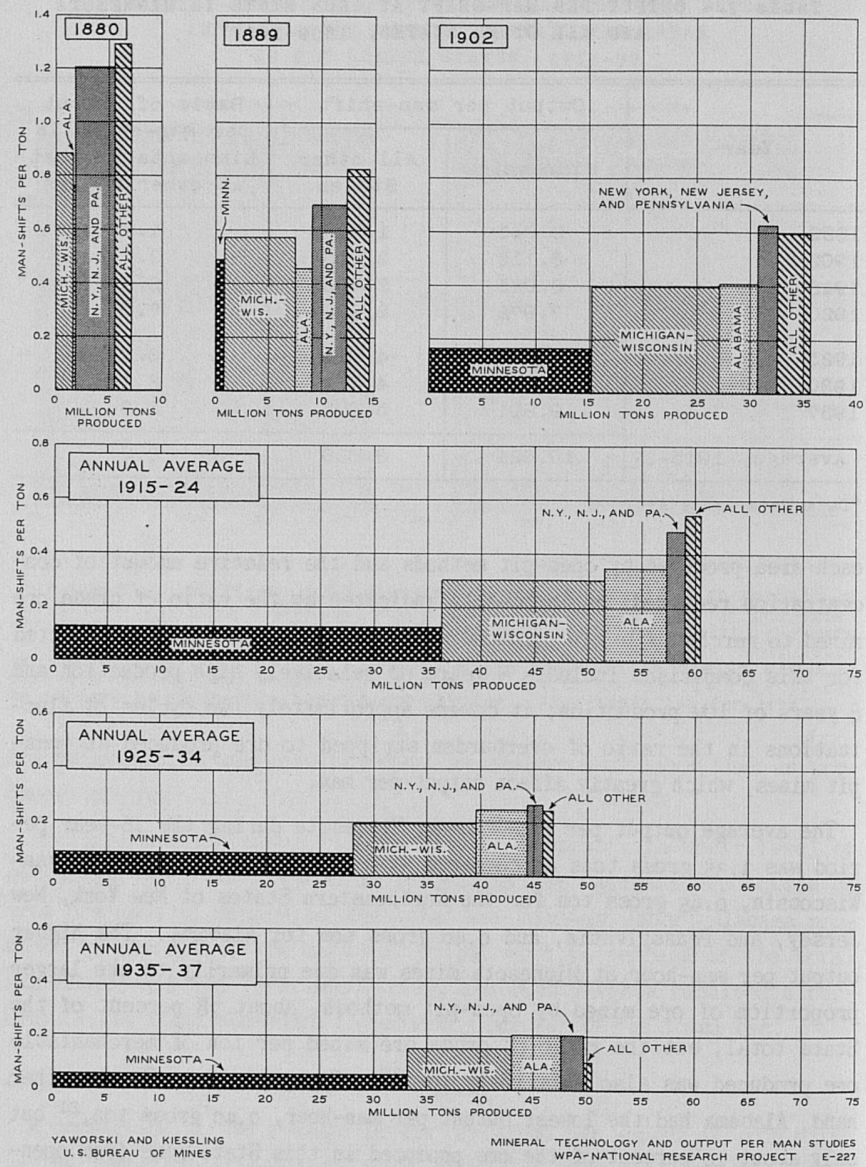
each area produced by open-pit methods and the relative amount of concentration required, as is roughly indicated by the ratio of crude ore mined to merchantable ore produced. The 16-year period 1922-37 selected for this comparison includes 8 years of relatively high production and 8 years of low production; it covers approximately two cycles of fluctuations in the ratio of overburden stripped to ore produced at open-pit mines, which greatly affect output per man.

The average output per man-hour in Minnesota during the 16-year period was 1.35 gross tons as compared with 0.58 gross ton for Michigan-Wisconsin, 0.45 gross ton for the Northeastern States of New York, New Jersey, and Pennsylvania, and 0.40 gross ton for Alabama. The higher output per man-hour at Minnesota mines was due primarily to the larger proportion of ore mined by open-pit methods, about 78 percent of the State total, but the ratio of crude ore mined per ton of merchantable ore produced was also relatively low.[20] (See table 8.) On the other hand, Alabama had the lowest output per man-hour, 0.40 gross ton,[21] but only about 10 percent of the ore produced in this State came from open-pit mines. Moreover, Alabama mined the largest amount of crude ore

[20]It should be noted also that in Minnesota output per man-hour at open-pit mines was usually higher and at underground mines always higher than at similar mines in other States (see table A-6), and that ore-concentration methods in Minnesota are generally simpler and require less labor than in other States. Also, mines in Minnesota are much larger than in other States. In 1937 the average annual output per mine in Minnesota was 576,000 gross tons as compared with 189,000 gross tons for all other States combined.

[21]If output per man were measured in terms of the iron content of the merchantable ore produced, the figure for Alabama would be relatively lower, for the average iron content (natural) of the ore produced in Alabama during 1923-37 was only 37 percent as compared to 52 percent for the Lake Superior District and an average of 50 percent for the United States as a whole. (Data are from table A-4.) However, the lower iron content of the ore from Alabama is partly offset by the presence of lime, which makes the ore nearly self-fluxing.

Figure 11.- PRODUCTION, TOTAL MAN-SHIFTS, AND MAN-SHIFTS PER TON IN IRON-ORE MINING, 1880-1937, BY PRINCIPAL AREAS



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The influence of changes in the two determinants - unit labor requirements and volume of production - on total employment opportunities at iron mines in important producing States in the past half-century is shown in this diagram. The bars represent important iron-mining areas; their heights, the average number of man-shifts used per ton of ore produced; and their widths, average annual tonnage produced. Hence their surface areas represent the average annual number of man-shifts worked in the designated periods, selected to include as nearly as possible an equal number of years of high and low production.

Production increased to a peak during the World War period, but thereafter it ceased to grow and in depression years was sharply curtailed. The total number of man-shifts worked also rose to a peak in the World War period but decreased rapidly afterwards. The trends for the State of Minnesota are particularly striking. Whereas production rose more rapidly than in other States, the man-shifts required to produce a ton of ore were much lower. As a result, since 1915 Minnesota has produced 61 percent of the national output with only 36 percent of the total man-shifts. (See table A-4 for data.)

Table 8.- OUTPUT PER MAN-HOUR, RELATIVE IMPORTANCE OF OPEN-PIT MINING, AND RATIO OF CRUDE ORE MINED TO MERCHANTABLE ORE PRODUCED IN PRINCIPAL IRON-MINING STATES[a]

(Average for 1922-37)

State	Production of merchantable ore			Ratio of crude ore mined to total merchantable ore produced[b]
	Output per man-hour (gross tons)	Percent from open pits	Percent of United States total	
United States total	0.82	54.0	100.0	1.14
Minnesota	1.35	77.9	61.4	1.11
Michigan and Wisconsin	0.58	12.0	23.2	1.00
Alabama	0.40	9.7	10.3	1.53
New York, New Jersey, and Pennsylvania	0.45	41.9	3.2	1.29
All other States	0.45	52.8	1.9	1.50

[a]Data from reports of iron-mining companies to the U. S. Bureau of Mines.

[b]For all mines, including those that do not concentrate their ore. The ratio is affected both by the proportion of all ore that is concentrated and the amount of crude ore treated per ton of concentrate recovered.

per ton of merchantable ore.[22] The high output per unit of labor expended in Michigan and Wisconsin (0.58 gross ton) was attained despite a relatively low proportionate production (12.0 percent) from open-pit mines, for although the mines are mostly underground the nature of the ore deposits favors efficient exploitation. The ore mined, moreover, is of unusually high grade and thus far little concentration has been necessary. The remaining States are now relatively less important, accounting for only about 5 percent of the total production in the last 16 years.

Minnesota Shows the Most Rapid Gain in Labor Productivity

Not only is the average output per worker at Minnesota mines much higher than at mines in other States but it has also increased more

[22]The ratio of ore-bearing material to cleaned ore varies considerably, not only from one deposit to another but also from place to place in the same deposit. The ratio is unusually high for Alabama brown ores mined by open-pit methods. During 1923-37, for each ton of concentrate recovered at open-pit mines in Alabama about 6.6 gross tons of crude ore were sent to concentrators - as compared to 1.6 gross tons at all open-pit mines in Minnesota. Needless to say, the handling of almost 7 tons of crude material for every ton of merchantable product from open-pit mines depresses considerably the average output per man in Alabama. During 1915-37 the average output of merchantable ore per man-hour at open-pit mines in Alabama was a little more than half as high as in the case of underground mines, whereas in the rest of the United States the reverse was true, and output per man at open-pit mines was more than three times as high as at underground mines. (See table A-6.)

rapidly. In 1889 the average output per man-shift in Minnesota was 1.3 times as large as in other States combined, but by 1937 it was 3.3 times as large. (See table 7 and figure 12.) During the 16-year period 1922-37 the average annual increase in output per man-hour at all iron mines in Minnesota was 0.07 gross ton, or about three times as large as in all other areas combined.[23] (See table 9.)

This relatively large annual increase in Minnesota was due to rapid technological progress at open-pit and underground mines and to a growth in the proportion of the total output of the State produced by open pits - from 76 percent in 1922 to 88 percent in 1937.

The forces influencing output per man may be summarized under two general heads - those associated with the geology or character and location of the ore deposits and those associated with techniques of ore mining and beneficiating. The discovery and exploitation of new, richer, and more accessible ore deposits has increased labor productivity, while the gradual depletion of the best deposits has tended to decrease it. Improvement in the art of winning and processing the ore through better

Table 9.- AVERAGE ANNUAL INCREASE IN OUTPUT PER MAN-HOUR AT IRON MINES IN THE UNITED STATES, BY AREA AND TYPE OF MINE, 1922-37[a]

Area and type of mine	Average annual increase in output per man-hour[b] (gross tons)	Production of merchantable ore, 1922-37		
		Percent of United States total	Percent of total in area from open pits	Percent of total in area from open pits
Minnesota	0.070	61.4	77.9	77.9
All other areas	.023	38.6	15.9	15.9
Michigan and Wisconsin	.022	28.2	12.0	12.0
Alabama	.021	10.3	9.7	9.7
New York, New Jersey, and Pennsylvania	.022	3.2	41.9	41.9
All other States	.070	1.9	52.8	52.8
United States	.043	100.0	54.0	54.0
Open-pit mines	.094	54.0	-	-
Underground mines	.017	46.0	54.0	-

[a] Based on data in tables A-4 and A-5.

[b] Computed for the 16-year period by the method of least squares.

[23] "All other States", as shown in table 11, had as large an annual increase in output per man as Minnesota, but they accounted for less than 2 percent of the increase in total output. The rapid increase in these States reflects a rapid relative growth in open-pit mining.

rapidly. In 1889 the average output per man-shift in Minnesota was 1.3 times as large as in other States combined, but by 1937 it was 3.3 times as large. (See table 7 and figure 12.) During the 16-year period 1922-37 the average annual increase in output per man-hour at all iron mines in Minnesota was 0.07 gross ton, or about tnree times as large as in all other areas combined.[23] (See table 9.)

This relatively large annual increase in Minnesota was due to rapid technological progress at open-pit and underground mines and to a growth in the proportion of the total output of the State produced by open pits - from 76 percent in 1922 to 88 percent in 1937.

The forces influencing output per man may be summarized under two general heads - those associated with the geology or character and location of the ore deposits and those associated with techniques of ore mining and beneficiating. The discovery and exploitation of new, richer, and more accessible ore deposits has increased labor productivity, while the gradual depletion of the best deposits has tended to decrease it. Improvement in the art of winning and processing the ore through better

Table 9.- AVERAGE ANNUAL INCREASE IN OUTPUT PER MAN-HOUR AT IRON MINES IN THE UNITED STATES, BY AREA AND TYPE OF MINE, 1922-37[a]

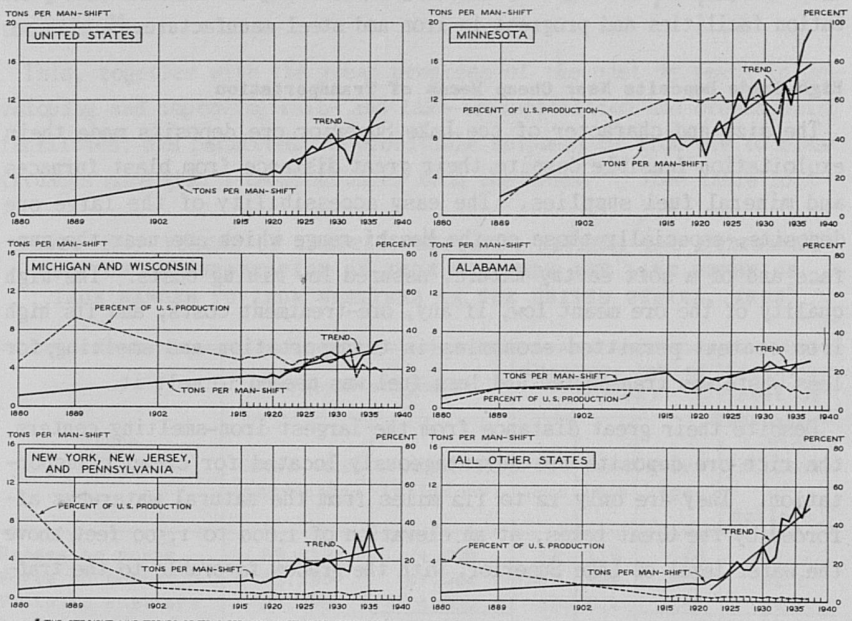
Area and type of mine	Average annual increase in output per man-hour[b] (gross tons)	Production of merchantable ore, 1922-37	
		Percent of United States total	Percent of total in area from open pits
Minnesota	0.070	61.4	77.9
All other areas	.023	38.6	15.9
Michigan and Wisconsin	.022	23.2	12.0
Alabama	.021	10.3	9.7
New York, New Jersey, and Pennsylvania	.022	3.2	41.9
All other States	.070	1.9	52.8
United States	.043	100.0	54.0
Open-pit mines	.094	54.0	-
Underground mines	.017	46.0	-

[a] Based on data in tables A-4 and A-5.

[b] Computed for the 16-year period by the method of least squares.

[23] "All other States", as shown in table 11, had as large an annual increase in output per man as Minnesota, but they accounted for less than 2 percent of the total output. The rapid increase in these States reflects a rapid relative growth in open-pit mining.

Figure 12.- OUTPUT OF MERCHANTABLE ORE PER MAN-SHIFT AND THE RELATIVE IMPORTANCE OF PRINCIPAL AREAS IN IRON-ORE MINING IN THE UNITED STATES, 1880-1937*



* THE STRAIGHT-LINE TRENDS OF TONS PER MAN-SHIFT WERE COMPUTED FOR THE YEARS 1922-37 BY THE METHOD OF LEAST SQUARES.

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Although output per worker increased in all of the important iron-mining States in the past half-century, the rising trend for the United States reflects also the concentration of production in mines having the lowest unit labor requirements. Especially important was the rapid increase, prior to the World War, in the share of the national output produced by Minnesota - from 6 percent in 1889 to about 60 percent in 1915 and thereafter. In Minnesota, furthermore, the average output per worker was much higher and increased much faster than in other States. Most of the ore in Minnesota, a much larger proportion than in other States, is produced by open-pit methods and at large-scale operations. (See table A-4 for data.)

ordering of the work - and especially through the use of more and better mechanical equipment - has increased output per man; thus far, together with discovery, it has been a more powerful force than depletion. Productivity has risen almost continuously over the past 57 years, but the relative importance of the above forces influencing this rise has changed. Prior to the World War the major factor in raising the average labor productivity was the discovery and exploitation of richer and more accessible deposits; after the war the major development of the new ore deposits was practically completed, and the principal factor was advancing technology and its application at large-scale operations.

OTHER FACTORS IN THE DEVELOPMENT OF THE LAKE SUPERIOR DISTRICT

Although comparatively easy mining, as reflected by high output per man, was important in the growth of iron mining in the Lake Superior

District, the development of this area was also influenced by powerful economic and technical changes extending beyond the iron mines. Of special significance were the development and improvement of transportation facilities and progress in iron and steel manufacture.

High-Grade Deposits Near Cheap Means of Transportation

The size and character of the Lake Superior ore deposits made their exploitation feasible despite their great distance from blast furnaces and mineral fuel supplies. The easy accessibility of the large ore deposits, especially those on the Mesabi range which are near the surface and of a soft earthy nature, assured low mining costs. The high quality of the ore meant low, if any, ore-treatment costs, and its high iron content permitted economies in transportation and smelting, for less waste was transported and less fuel was needed to melt it.

Despite their great distance from the largest iron-smelting centers, the rich ore deposits are advantageously located for cheap transportation. They are only 12 to 112 miles from the natural waterways afforded by the Great Lakes, at an elevation of 1,000 to 1,500 feet above the water level of Lake Superior, with the grades favorable to the traf-

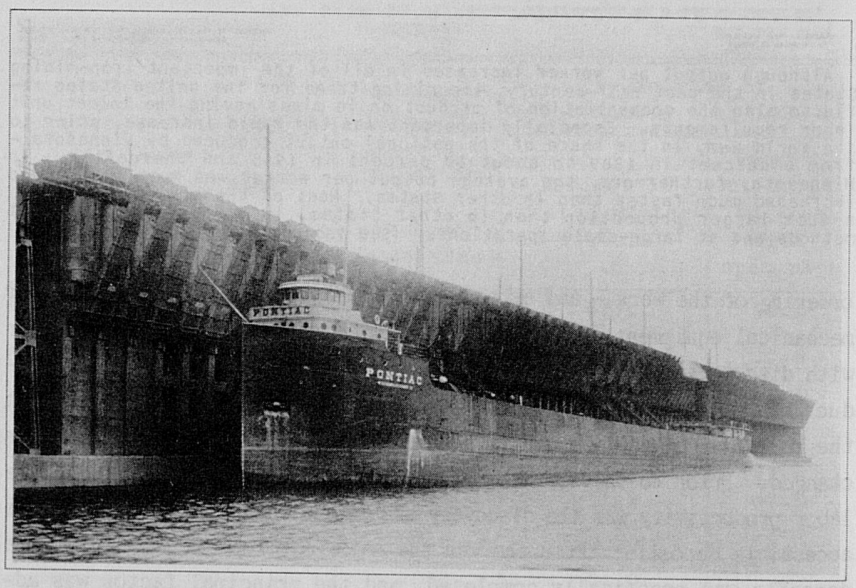


FIGURE 13.- MODERN ORE-LOADING DOCK AND ORE FREIGHTER

This picture shows a vessel at a modern dock at Marquette, Michigan, about to take on a cargo of iron ore. Drop-bottom ore cars may be seen on the dock ready to drop their loads into ore pockets underneath. The ore from these pockets is then loaded through chutes into the holds of ore freighters. Expensive ore-handling and transporting facilities like these have helped to make the Lake Superior District preeminent in the iron-mining industry of the United States.

fic.[24] Four-fifths of the ore journey from mines to blast furnaces is by water, and the ore is brought nearer to coal resources and iron and steel markets at about one-tenth the average railroad charge per ton-mile.[25]

This, together with the great progress of the past 75 years in developing and improving rail- and lake-transportation and ore-handling facilities, has permitted the profitable shipment of iron ore to blast furnaces more than a thousand miles from the mines.[26] (See table 10.)

Table 10.- VOLUME OF TRAFFIC, DISTANCE HAULED, AND ESTIMATED COST OF TRANSPORTATION OF IRON ORE FROM THE LAKE SUPERIOR IRON RANGES TO IRON SMELTERS IN THE UNITED STATES, 1923[a]

Stage	Iron-ore shipments		Distance hauled (miles)			Estimated cost of transportation[b] (millions of dollars)
	Gross tons (thousands)	Ton-miles (millions)	Minimum	Maximum	Average	
Ranges to ports	59,019	4,006	12	119	68	52.0
Ports to ports	58,590	47,044	159	988	803	42.5
Ports to smelters	34,378	4,980	59	572	145	39.0
Ranges to smelters		56,030			1,016	133.5

[a] Data from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps in cooperation with U. S. Shipping Board, 1926), pp. 284-9, 297-300.

[b] Includes all handling charges. In estimating the cost of transportation from ranges to ports, 1925 rail rates were used. These rates were essentially those in effect in 1923. The Lakes rates used were those of 1923.

Improvements in Haulage and Handling Methods

At strategic points along the route from the iron mines to blast furnaces, elaborate transportation and ore-loading and -unloading facilities

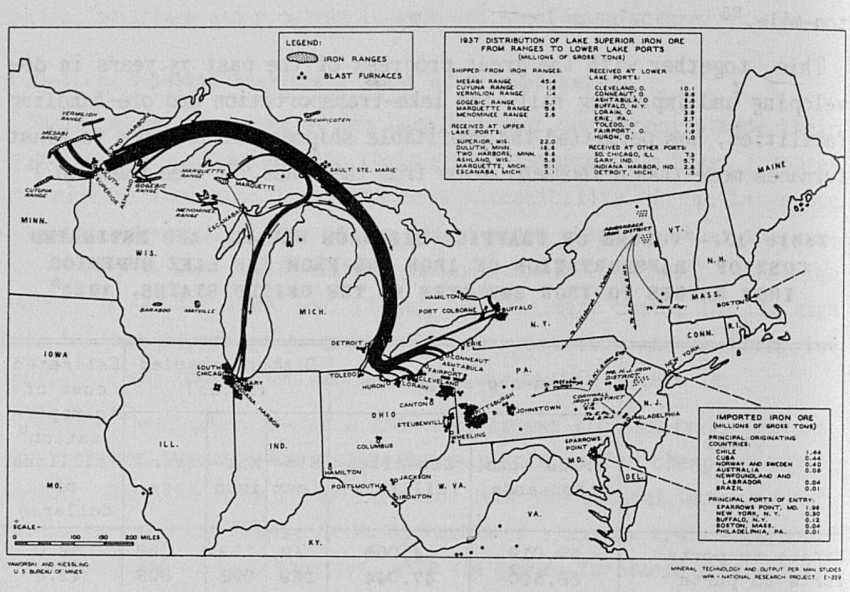
[24] *Special Reports of the Census Office*, "Mines and Quarries: 1902" (U. S. Dept. Com. and Labor, Bur. Census, 1905), p. 409.

[25] As shown in table 10, the transportation cost for the Lakes haulage of around 47 billion ton-miles of ore traffic was 42.5 million dollars, or about $0.90 per 1,000 ton-miles, compared with 91 million dollars for almost 9 billion ton-miles by rail, or about $10.13 per 1,000 ton-miles. See also A. E. R. Schneider, "Transporting Iron Ore," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929), p. 766.

[26] Around 1880, when the Lake Superior District produced only 24 percent of the national iron-ore production (as compared with 86 percent in 1923), the average distance of haulage of all ore produced in the United States was about 400 miles. See James M. Swank, *History of the Manufacture of Iron in All Ages, and Particularly in the United States for Three Hundred Years, From 1585 to 1885* (Philadelphia, Pa.: James M. Swank, 1884), p. 376.

It has been estimated that the cost of transporting iron ore from the Lake Superior mines to blast furnaces in 1923 amounted to about 134 million dollars (see table 10); but if the ore had been transported all the way by rail at the ton-mile rate then in force from the Mesabi range to St. Louis, Missouri, for instance, the total cost would have been about twice as large. See *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps in cooperation with U. S. Shipping Board, 1926), pp. 297-8.

Figure 14.- DISTRIBUTION OF LAKE SUPERIOR IRON ORES FROM IRON RANGES TO LOWER LAKES PORTS AND CONSUMING CENTERS, 1937



The Lake Superior District produces about 85 percent of the total output of iron ore in the United States. The dominant position of this area is partly due to its fortuitous natural advantages of rich and easily accessible ore deposits situated at distances ranging from only 12 to 112 miles from the natural waterways afforded by the Great Lakes. Four-fifths of the 1,000-mile ore journey from mines to blast furnaces is by water, bringing the ore nearer to coal resources and iron and steel markets at a transportation cost of only about one-tenth the usual railroad charge per ton-mile. Moreover, at strategic points along the route from the iron mines to blast furnaces, there have been developed efficient transportation facilities that handle enormous quantities of iron ore cheaply and expeditiously.

Data are from the following sources: Ore shipments from *Distribution of Lake Superior Iron Ores and of Eastern and Imported Ores, Season 1937* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., July 1, 1938); location of blast furnaces from *Directory of the Iron and Steel Works of the United States and Canada* (22d ed.; New York: American Iron and Steel Institute, 1935).

have been developed and greatly improved. The ore is first hauled by one of eight railroads to well-equipped ore-shipping docks constructed at six different ports where it is dumped into bins or pockets and loaded by gravity into the holds of Lakes ore freighters. The vessels carry the ore to receiving docks at lower Lakes ports where the ore is either conveyed to stock piles or is loaded directly into ore trains and hauled to smelters. (See figure 14.) In this way enormous quantities of ore are handled cheaply and expeditiously. The remarkable progress in the development and improvement of transportation and handling of Lake Superior ore in the past 75 years is briefly reviewed in appendix B.

Frequent Handling Has Permitted Delivery of More Uniform Grade of Ore

The circumstances surrounding iron-ore mining, handling, and transportation from the Lake Superior District to smelters have proved a decided advantage in securing delivery to blast furnaces of ores nearly uniform in composition - an increasingly important factor in efficient operation of modern furnaces. All iron-ore deposits vary more or less in different portions in their content of iron, phosphorus, silica, manganese, alumina, and moisture. Blast furnaces which had formerly depended upon local mines for their ore supply suffered from greater irregularity in the quality of raw material than when the ore delivered to them came longer distances and was thoroughly mixed as the result of frequent handlings. The large deposits exploited in the Lake Superior District permitted the taking of ore from several portions of the deposit simultaneously. The rigorous climate of this area prevented water transportation of ore during the wintertime; thus the ore mined at underground operations had to be stock-piled and removed later, the process serving to mix the ore. The necessity of transporting the ore partly by land and partly by water afforded an opportunity to mix the ores frequently: in trains going to the ore docks, in the ore pockets of the docks at the upper Lakes ports, in the holds of ore vessels, in the stock piles or trains at receiving docks at the lower Lakes ports, and in ore piles at blast furnaces. Each additional handling served to mix the ore more thoroughly and helped to assure delivery of a more uniform grade to blast furnaces.[27]

Improvements in Smelting and Steel Making Favored Use of Lake Superior Ores

Prior to 1880 iron was manufactured on a relatively small scale; blast furnaces were small and scattered widely throughout the eastern part of the United States and were dependent mostly on local supplies of comparatively lean iron ore and charcoal fuel. But as fuel timber became scarce, many of the early smelting furnaces had to be abandoned. With increasing success in the use of mineral fuel - at first raw coal and later coke - iron was manufactured more efficiently and on a larger scale. Pig-iron production was concentrated more and more in fewer furnaces with more ample capacities.[28] In the census year of 1880, 681

[27] For an illuminating account of the increasing importance of ore grading and a description of the methods generally employed in grading Lake Superior ores, see E. P. Bayer, "Grading Lake Superior Iron Ores," *Engineering and Mining Journal*, Vol. 139, No. 3 (Mar. 1938), pp. 50-1.

Footnote 28 appears on following page.

blast furnaces produced 3,376,000 gross tons of pig iron.[29] Since then the number of blast furnaces has steadily declined while their capacities have been constantly increased, until in 1937, 241 furnaces - of which only 95 were active - produced more than 37 million gross tons of pig iron.[30] In 1880 the largest blast furnaces produced about 1,000 gross tons of pig iron per week;[31] the capacities of average present-day blast furnaces are three or four times as great, and some of the largest can now produce more than 1,000 gross tons per day.

The increasing size of blast furnaces and the demand for larger quantities of iron of better and more uniform quality called for larger and more reliable supplies of iron ore of higher and more uniform grade. The rich deposits in the Lake Superior District fulfilled this need. The ore reserves were sufficiently plentiful to last for many years and encouraged the construction of larger and more permanent iron- and steel-manufacturing establishments within easy reach of lower Lakes ports. The large capital investments[32] in iron and steel works were made with assurance that plentiful future supplies of iron ore and other needed materials would be available, for the principal iron- and steel-producing companies acquired ore reserves that assured them of adequate supplies for as many as 20 to 50 years in the future - and the bulk of the iron mines in the Lake Superior District are now owned or controlled by these vertically integrated companies.[33] Originally the soft ores of the Mesabi and other ranges in the Lake Superior District were considered unsatisfactory for blast-furnace use; but further experience in smelting them, alterations in the design of blast furnaces to suit the ore, and treatment of the ore to adapt it to the furnaces overcame these difficulties; most of the ore now smelted is of this character.

The consumption of iron and steel was greatly increased prior to the World War by the general rapid industrial development of the United

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[28] An important factor in the development of large furnaces was the exploitation of the Pittsburgh coal bed with its unsurpassed Connellsville coking coal. This coal yields a large proportion (60 to 70 percent) of coke strong enough to support the enormous weight of the blast-furnace charge and porous enough to allow the free passage of air. See Erich W. Zimmermann, *World Resources and Industries* (New York: Harper & Bros., 1933), pp. 620-1.

[29] Swank, *op. cit.*, pp. 380-1.

[30] *Annual Statistical Report of the American Iron and Steel Institute for 1937* (New York: American Iron and Steel Institute, 1938), pp. 7, 12.

[31] Swank, *op. cit.*, p. 404.

[32] The total capital investment in the iron and steel industry, which during most of 1937 employed more than half a million workers, was 4½ billion dollars. A single average blast furnace costs about 2½ million dollars. To let such a furnace stand idle means so heavy a loss on fixed charges that operation even at unremunerative prices may be preferred. See *Iron and Steel* (U. S. Tariff Com., Report No. 128, 2d ser., 1938), p. 86. See also Zimmermann, *op. cit.*, p. 591.

[33] About 80 percent of the available Minnesota ore reserves in 1933 were owned, operated under lease, or controlled by steel corporations. See *Iron and Steel*, p. 353.

States and particularly by the rapid expansion of the railroad network. The consumption of Lake Superior ore was also increased through the introduction (after the middle of the nineteenth century) and the subsequent improvement of the Bessemer and open-hearth steel-making processes that made possible mass production of steel in the United States.[34] Although these developments resulted in increasing the demand for iron ore from all areas, they particularly hastened the exploitation of the rich and easily accessible Lake Superior deposits, for it is to be noted that the expansion of the iron and steel market was westward, away from the seaboard and foreign sources of iron ore. Moreover, the invention of the basic lining (in the last quarter of the nineteenth century) and its adaptation to open-hearth furnaces for use with charges of molten pig iron made from so-called non-Bessemer ore (containing appreciable amounts of phosphorus) further paved the way for the rapid development of the Lake Superior District, since most of the ores in this district are of the non-Bessemer variety.[35]

New Blast Furnaces Erected Near Lakes Ports

With the growth of the automobile industry and the general industrial development of the midwestern area of the United States, new, modern blast furnaces were erected at points more convenient to raw materials and markets. This has meant the expansion of iron- and steel-producing centers northward and westward from Pittsburgh to the Cleveland-Detroit-Chicago area. The new centers depend entirely on the Lake Superior ore deposits and are located where a long rail haul from Lakes ports is unnecessary. Fuel economies in ore smelting - achieved by raising the temperature of the hot blast, by using more powerful blowing engines, and by erecting higher and larger furnaces - have reduced the importance of locating blast furnaces near coal supplies. These improvements, together with the use of richer and better-sized ores, greatly increased the yield of the furnaces while decreasing their consumption of fuel per ton of pig iron produced.

Thus, in the quarter-century prior to the World War, the westward expansion of the Nation and the growth and progress of its heavy industries[36] were related causes contributing to the rapid development of

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[34] The open-hearth process of steel making, which, in quantity of steel produced, overtook the Bessemer process by 1908, permitted the use of accumulated stocks of iron and steel scrap (heretofore of little value). One-half or more of the open-hearth charge consists of scrap and the remainder of pig iron.

[35] For a further discussion of the development of steel-making processes in the United States, see *Iron and Steel*, pp. 48-50, 84; see also Zimmermann, *op. cit.*, pp. 597-600.

Footnote 36 appears on following page.

Lake Superior iron mines, where both employment and labor productivity increased. After the war the arrested demand for iron ore curbed the further growth of iron-ore production. Technical progress in mining, however, continued to increase output per man, and employment at iron mines declined.

In the following chapters the major trends in production, employment, and output per man are reviewed separately for open-pit and underground iron mining.

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[36]The augmentation of the labor supply resulting from immigration to this country from southeastern Europe, which reached its peak around 1905-14, may be mentioned as another circumstance that aided the rapid development of iron mining in the Lake Superior District. One observer in 1911 stated: "Without immigrants the mining companies on the Minnesota ranges would never have been able to open the mines, or if successful in opening them, to continue their operation. There has never been enough native labor in the northwest to supply the demand of the operators, and labor is very difficult to secure for the low class of work demanded in the open-pit mines of the Mesabi.

"The history of immigration to the iron region, and the history of the development of the ore range, go hand in hand, and one can not be written without the other." In 1911 the most prevalent nationalities employed at iron mines, in the order named, were: Finns, Slovenians, Croatians, Italians, Poles, Slovaks, Montenegrins, Norwegians, Swedes, and English. See W. J. Lauck, "Iron-Ore Mines on Mesabi and Vermilion Ranges," *Mining and Engineering World*, Vol. XXXV, No. 26 (Dec. 23, 1911), p. 1269.

CHAPTER IV

CHANGES IN LABOR REQUIREMENTS AND TECHNOLOGY AT OPEN-PIT MINES*

As indicated in the previous chapter, an increasing proportion of the iron ore produced in the United States in the past half-century has come from open pits. Since average unit labor requirements at these mines are much lower than at underground mines, this trend has been an important factor both in preventing a faster increase of employment in the iron-mining industry prior to the war period and in hastening its decline afterward.

The most rapid growth of open-pit mining coincided with the discovery and quick development, beginning in 1892, of the Mesabi range in Minnesota, where the ore deposits are unusually well adapted to open-pit mining. By 1912, only 20 years after the first ore shipment, the Mesabi range was producing more than half of all the iron ore produced in the United States and more than four-fifths of the total output from open pits. Thereafter the development of the Mesabi range was less spectacular, and the increase in the proportion of the total output produced by open-pit mines was much slower. But progress in open-pit-mining techniques continued apace, and the growth in average output per worker was accelerated rather than retarded.

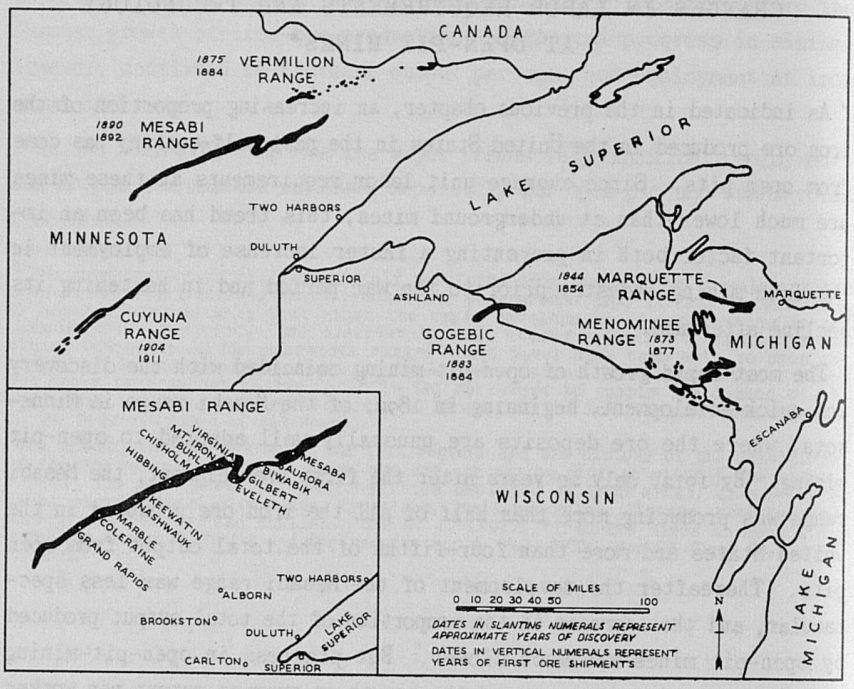
During the 23-year period 1915-37, for which data are available, average output of merchantable ore per man-hour at open-pit operations was about three times as large as at underground mines (see table 11),[1] and the difference was even larger in more recent years as output per worker at the former increased more rapidly.[2] As a result, in the past

*N. Yaworski and O. E. Kiessling.

[1]In many cases output per man at open-pit mines is lower than at the most productive underground operations. (See, for example, table A-18.) In such instances, however, an explanation may be found in some unusual and perhaps temporary circumstance associated with the particular open-pit operation. The mine in question may be a very small operation worked by hand methods; it may be undergoing an extraordinary amount of development work, perhaps changing over to a new mining system; it may have encountered some natural difficulty or accident; or, it may be near the end of its life and in the process of mining out the last remnants of the ore body at the bottom of the pit or in the benches. In Alabama output per man at open-pit mines is consistently lower than at underground operations because of the unusually lean material mined from the brown-ore deposits, necessitating removal and concentration of almost 7 tons of crude ore for each ton of merchantable concentrates recovered during 1923-37. If the man-hour output were to be expressed in terms of tons of crude ore mined (instead of merchantable ore produced), it would be much higher at open-pit mines than at underground operations in Alabama as well as in other States.

[2]For example, the ratio of output per man-hour at open-pit mines to output per man-hour at underground mines was 2.8 in the 5-year period 1915-19, as compared with 3.9 during 1933-37, the last 5 years for which data were available. (See table A-5 and also table 9.) This relatively high average output per man at open-pit mines was maintained despite the necessity for concentrating a larger proportion of their output than at underground mines. For example, during 1936-37 concentrated ore represented 21 percent of the total merchantable ore produced by open-pit mines as compared with 7 percent for underground mines. (See table A-10.)

Figure 15.- IRON RANGES OF LAKE SUPERIOR DISTRICT



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During the past 25 years about 85 percent of the iron ore produced in the United States was mined in the Lake Superior District. Of the six iron ranges in this district, the Mesabi range was by far the most important both from the standpoint of the quantity of ore produced and the size of the available ore reserves. Although its discovery and development are comparatively recent, it has accounted for 60 percent of the total shipments from iron mines in the Lake Superior District and contains 84 percent of the estimated ore reserves still available there. The Mesabi range also possesses the advantage of having the most accessible ore deposits, and nine-tenths of its production is mined by low-cost open-pit methods.

According to W. L. Taylor: "Roughly, the Mesabi can be divided into three sections, as follows:

"(1) Eastward from Mesaba the formation is little altered, hard and siliceous, much of the iron occurring as finely disseminated magnetite.

"(2) Between Mesaba and Keewatin the ore which occurs as hematite and limonite is so highly concentrated that practically all of it is shipped directly without beneficiation, except in some cases where the ore is crushed and screened.

"(3) West of Keewatin a large part of the ore is not sufficiently rich in its crude state to be merchantable. These ores, which are mixed with sand, decomposed taconite and taconite, are called 'wash ores.'" (See "The Mesabi Iron Range," *The Mining Congress Journal*, Vol. 15, No. 10 [Oct. 1929], p. 789.)

score of years open-pit mines produced about half of the total output of merchantable ore with about one-fourth of the total number of employees and somewhat fewer days worked per year.[3] Moreover, despite an

[3]During 1915-37, employees at open-pit mines worked an average of 240 shifts per year as compared with 268 shifts at underground mines. This was due to the fact that most of the open-pit mining is in the Lake Superior District where mining operations are suspended during the winter, although it is customary to employ a part of the labor force in repair shops and in overburden stripping preparatory to mining during the next shipping season. On the other hand, open-pit mines [*Con.*]

Table 11.- AVERAGE OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES DURING 1915-37, BY STATE[a]

State	Percent of total output from -		Merchantable ore per man-hour (gross tons)		
	Open-pit mines	Underground mines	Open-pit mines	Underground mines	Ratio of open-pit to underground tons per man-hour
United States total	100.0	100.0	1.319	0.436	3.0[b]
Minnesota	88.2	31.7	1.633	.580	2.8
Michigan and Wisconsin	5.3	44.1	1.268	.444	2.9
Alabama	2.1	17.9	0.226	.373	0.6
All other States	4.4	6.3	0.536	.229	2.3

[a]Based on table A-6.

[b]The ratio is higher for the United States than for the component States. This is because output per man at both open-pit and underground mines was considerably higher in Minnesota than in all other States and because Minnesota produced 88 percent of all ore from open pits and only 32 percent of all ore from underground mines.

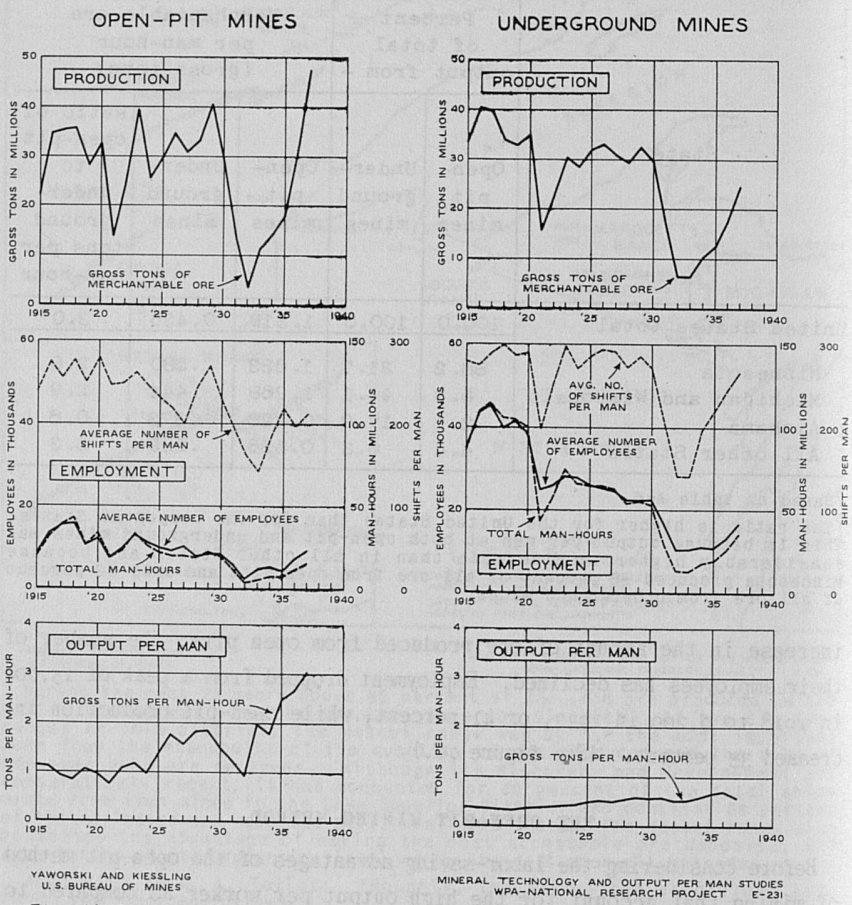
increase in the amount of ore produced from open pits, the number of their employees has declined. Employment dropped from a peak of 15,700 in 1918 to 9,200 in 1937, or 41 percent, while open-pit production increased 33 percent. (See figure 16.)

THE OPEN-PIT MINING METHOD

Before considering the labor-saving advantages of the open-pit method of mining that account for the high output per worker as compared to underground mining, it is helpful to describe briefly the former method. Open-pit mining refers to the removal of ore from an open pit entirely exposed to daylight. Obviously, it can be used economically only in those areas where the ore deposits are near the surface, as on the Mesabi range. Since the ore body is covered by a layer of earth or rock, called overburden, stripping, or glacial drift and varying in thickness from less than 10 to several hundred feet, the extraction of the ore itself must await the removal of the overburden. At some of the earliest operations the ore was found at the "grass roots", but at present-day operations the overburden encountered is more frequently 50 to 150 feet thick.

[3][*Con.*]have averaged 9.5 hours per shift compared to 8.7 hours per shift at underground mines. The average number of hours worked per man per year, therefore, was 2,280 at open-pit mines and 2,332 at underground mines. (See table A-5.)

Figure 16.- PRODUCTION, EMPLOYMENT, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES IN THE UNITED STATES, 1915-37



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The difference in total and unit labor requirements of open-pit and underground methods of mining is very striking. Although in the past 23-year period for which data were available open-pit mines produced 51 percent of the total output of merchantable ore, they employed only 26 percent of the total number of employees, working a little less time per year than at underground mines. Moreover, despite an increase in production from open pits, employment at these mines has been declining. The principal explanation of these trends, of course, is the comparatively high output per man at open-pit mines, which, during the 23-year period, averaged three times as high as at underground mines - and is even larger in more recent years - because output per man at open-pit mines increased more rapidly. (See table A-5 for data.)

The first problem in open-pit mining, as in underground mining, is to determine through exploratory drilling or test pitting the size and extent of the ore body and the grade of the ore. Similarly, a suitable place must be found for dumping the overburden or waste, care being taken to build the dump as near as possible to the open pit but on land that does not overlie valuable ore deposits. Moreover, the dump site must be located where it will not interfere with approaches to the pit.

After this preliminary planning of the mine lay-out and after choice of the haulage system and equipment, the overburden is removed from an area over the ore body sufficient to permit uninterrupted ore mining for at least one or two seasons. A considerable amount of overburden may also have to be removed from around and beyond the outer limits of the ore body - an amount varying with the anticipated ultimate depth of the pit, the attainable bank slopes, and approaches to be cut. The overburden is "stripped" or loaded by power shovels into dump cars and hauled away to waste dumps. Each shovel is served by two or three trains in order to minimize loading interruptions. The overburden is removed in a series of cuts, the number depending upon the size of the shovel and the thickness of overburden. Thick or deep overburden is removed in a number of successive levels, the operations being conducted on a series of benches so as to provide a means of entrance and exit for trains on tracks with suitable grades. The usual method of stripping requires considerable track laying or shifting in the pit and on the waste dumps, both for the shovels and the trains; although, as observed later, newer shovels are equipped with caterpillar traction, and more recently at some mines trucks, tractor wagons, or belt conveyors have eliminated trackage entirely. Stripping power shovels frequently encounter granite boulders, sometimes as large as 12 feet in diameter. Before these can be loaded and dumped, they must be pulled or chained out and left in the wake of the shovel for reduction into smaller pieces by drilling and blasting.

When a sufficient area has been stripped, the ore itself is then excavated according to plan. Most of the ore bodies require loosening prior to loading; for this purpose vertical holes are drilled, charged with explosives, and blasted well ahead of the power shovels so as not to delay loading operations. The haulage system is adapted to the particular physical conditions encountered and the available equipment considered most suitable. The character of the ore; its ability to stand up in steep slopes; the present and anticipated width of the pit; and the size, shape, and depth of the ore body - all determine the track arrangement, which is laid out either in a spiral or switch-back (zigzag) pattern or in a combination of the two. Enough track must be laid and a sufficient number of benches developed to allow appropriate grades (ranging from 0 to 4 percent in steam haulage) and at the same time to minimize both the amount of ore tied up in track benches and the quantity of overburden or other waste material that must be removed per ton of ore mined. Toward the end of the life of an open pit, especially one that is deep and narrow, it is frequently necessary to resort to

a radical change in methods, such as haulage to a shaft and hoisting, the use of electric locomotives, and, more recently, trucks, scrapers, or belt conveyors.[4]

LABOR-SAVING ADVANTAGES OF OPEN-PIT MINING

The relatively low unit labor requirements of open pits in comparison with underground operations are explained by their numerous labor-saving advantages. Because the ore body is near the surface and usually of large lateral extent, it is easily prospected, delineated, and sampled, resulting in a more thorough knowledge of the deposit than is usually obtained about ore bodies mined by underground methods. This permits more orderly planning and development of the mine and more accurate estimation of probable operating costs.

Also, the materials excavated need be raised only a short distance,[5] and their horizontal and vertical transportation is usually accomplished simultaneously by haulage over inclined roadways; high-grade ore is loaded directly into relatively large railroad cars used to ship the ore from the mines. In contrast, ore transportation in underground mines requires much more frequent handling and transfer; and materials must be hoisted or lowered over longer distances in cages or skips of relatively small size, making this function the bottleneck of underground operations.

The nearness of the open-pit ore body to the surface likewise permits easier drainage. Although open pits form large catchment basins and sometimes necessitate the pumping of large quantities of water, this water need be raised only a comparatively short distance, and larger, though relatively cheaper, pumping equipment may be used.

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[4]Among the many variations from the usual power-shovel-loading and railroad-haulage method, "milling" has been the most important. By this method the overburden was removed by power shovels, as in open-pit mining, but the ore itself was drawn through "raises" or vertical openings which were connected with "drifts" or horizontal underground passages located some distance below the top of the ore and which led to a shaft usually well off the ore body. The ore was loosened by drilling and blasting, scraped to (or sometimes steam-shoveled into) the raises, thus forming large sinks or craters, and then hauled underground to the shaft and hoisted, as in underground mining. Output per man at mines using the milling method was usually higher than at mines using the customary underground methods, but it was not so high as at the regular open-pit mines. Recently a system of milling was introduced on the Mesabi range in Minnesota whereby the ore is brought to the surface by means of belt conveyors operating over inclined passageways.

[5]According to reports from iron-mining companies to the U. S. Bureau of Mines, the weighted average maximum vertical depth of open-pit mines in 1937, measured along the highest side wall (or bank) from the surface to the lowest adjoining bench, was 227 feet. These data cover mines producing 78 percent of the total merchantable ore produced from open pits. In contrast to this, the weighted average maximum vertical depth of shafts used for hoisting ore at 56 underground mines in 1937 was about 1,400 feet, and the average vertical depth from which material was hoisted at 51 of these mines was about 1,200 feet. These averages are based on data for mines that produced 86 and 81 percent respectively of the total merchantable ore produced by underground mines. (See table A-20.)

In comparison with the relatively cramped working quarters in underground mines, open pits have unlimited vertical and almost unlimited horizontal space. As a result, mining may be conducted on a mass scale with large and powerful drilling, loading, and haulage machinery, permitting large labor economies. Costly and laborious shaft sinking or underground tunneling to exploit ore bodies is unnecessary in open-pit mines except in a few cases, usually near the end of the life of a pit to recover ore remaining in the benches or at the bottom of deep or narrow pits. Moreover, timbering - which requires a large proportion[6] of the labor in underground mines and constitutes a fire hazard - is unnecessary in open pits, for the workings do not require artificial support. Even in those underground mines where the ore is mined by open stoping and artificial supports are not needed, ore or rock pillars must be maintained.

Blasthole drilling in open-pit mines is accomplished with much less labor and other cost than in underground mines, for more of the ore bodies are soft and all may be loosened by drilling and blasting fewer but deeper and larger holes capable of holding a larger quantity of explosives. A larger number of holes may be blasted simultaneously, the shattering effect resulting in more ground being loosened per hole, whereas in underground mining the number of holes that may be fired simultaneously is limited by the necessity for safeguarding walls and timber supports as well as the miners. Moreover, the breaking of ground in open-pit mining is facilitated by the presence of two and sometimes three free faces, and the easier down-hole drilling is sufficient. In contrast, the underground miner is frequently confronted with only one working face (or breast) from which the ore or rock must be carefully and skillfully blasted bit by bit, after the tedious drilling of many holes frequently pointing upward.[7]

Artificial ventilation is, of course, unnecessary at open-pit mines, and although the labor involved in ventilating mines is not large, the influence of proper ventilation on output per man through improving working conditions and reducing interruptions is an important factor.

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[6] About 10 percent of the underground employees were engaged primarily in timbering in underground mines in 1931, not counting the work of timbering performed by miners incident to their other activities. (See table A-16.) It was said in 1892 that the "'cost of timbering alone in many mines on the south shore of Lake Superior exceeds the total cost of mining millions of tons of ore on the Mesabi.'" (Horace V. Winchell, "The Mesabi Iron-Range," *Transactions of the American Institute of Mining Engineers*, Vol. XXI [1892-93], p. 686.)

[7] About 37 percent of the total number of employees in underground iron mines in 1931 were engaged chiefly in drilling and blasting. In addition to actual drilling and blasting, these workers spent considerable time in mucking, timbering, and in other miscellaneous activities. At open-pit mines, drilling and blasting employees constituted only about 7 percent of the total. (See tables A-15 and A-16.)

Proper ventilation of underground mines, moreover, forbids the use of steam or internal-combustion engines in underground workings, whereas open-pit mines are not limited in this respect and may employ these sources of power in addition to compressed air and electricity.

Similarly, artificial lighting is unnecessary at open-pit mines except when night shifts are operated; in underground mines lighting is a constant problem. Only in a few instances, as in large stopes that are lighted with large electric bulbs, is the underground miner freed of the necessity of tending his light. If he uses a carbide lamp he must interrupt his work occasionally to supply the lamp with water or carbide or to relight if after it has been blown out by the frequent underground air currents. If he is equipped with an electric light, his freedom of movement is partially restricted by the weight of the battery hung on his belt and by the cable attached to the light on his helmet. At best, lighting in underground mines cannot compare with the daylight of open pits, and better lighting also means more comfortable and safer working conditions and better supervision both of workmen and workings.

Open-pit mines are more flexible in operation and are more capable of rapidly contracting or expanding production when necessary. The maintenance cost of open-pit mines during the periods of shut-down is relatively low, involving not much more than the cost of a few watchmen and perhaps a pumping crew, although even the latter is sometimes dispensed with. The maintenance of an idle underground mine, however, requires a crew to operate pumps, to replace broken or rotted timbers, to guard against fire, and by other means to keep work places and passageways as well as equipment in proper working order.

It is also easier for open-pit mines to expand their production when the demand for ore justifies it.[8] In many cases production may be increased perhaps by the addition of another power shovel and other necessary equipment. Output may be greatly increased temporarily, even without much additional stripping of overburden, since usually enough ore is uncovered to permit uninterrupted mining for one or more shipping

[8]There is some question as to whether or not open-pit mines are more capable of adjusting their production to changes in the quality of ore required. In 1912 Charles E. van Barneveld, in his book, *Iron Mining in Minnesota* (Univ. of Minn., School of Mines Expt. Sta., Bull. No. 1, 1912), p. 44, stated: "In underground work the unit of operations is a party of two miners whose daily output may run up to 30 tons under very favorable conditions and there are from 25 to 40 or more working places to draw from. In open-pit mining the unit is a steam shovel with a capacity of several thousand tons and in a spotted ore-body it is very difficult to maintain desired grades without seriously affecting the economy of mining." At the time van Barneveld made the above statement, however, mining was carried on in open pits by the railroad type of steam shovel mounted on tracks, which was extremely difficult to move from one place to another. Today a large proportion of the power shovels are equipped with caterpillar traction and can move about easily to locations in the open pit containing ore of the grade desired or ores which can be mixed so as to obtain the desired grade.

seasons. On the other hand, the ability of underground mines to expand production quickly is limited. The number of their working places and transport avenues is kept as near as possible to the usual production requirements because the maintenance cost of excess capacity is relatively high for the same reasons as in the case of idle mines. Moreover, hoisting capacity - the bottleneck of underground operations - is similarly limited, and the sinking of a new shaft is, of course, a costly and time-consuming venture that may not be warranted by the temporary nature of increased demand for iron ore. Since a larger proportion of the working force at underground mines is skilled labor and the total labor requirements for a given increase in production are three or four times as large as at open-pit mines, underground mines may also experience difficulty in augmenting their labor force on short notice.

Finally, work in open pits is relatively healthful and safe, for the worker at all times has plenty of light and fresh air; he is not forced to work in cramped places and is relatively free of the hazard of injury by falling rock or ore, which is one of the most frequent causes of accidents underground.[9]

Not all the circumstances of the open-pit method of mining, however, are favorable. Among the chief disadvantages is the relatively high initial outlay of capital necessary for development purposes - mainly for removal of overburden where it is unusually thick. In some cases a relatively long period of development is necessary before ore can be extracted and a return on the investment realized. It is for these reasons that some of the earlier mining companies, with limited capital resources, decided upon the underground method of mining, even though the open-pit method would have been more economical in the long run. On the other hand, the acquisition of mining properties by companies with large financial resources has served to expand open-pit mining.

Another disadvantage of open-pit mines, especially in the Lake Superior District where most of them are located, is their susceptibility to interruption by cold or inclement weather. During the winter it is customary for open-pit mines in the Lake Superior District to suspend mining operations altogether,[10] both because of cold weather and deep snow and because ice on the Great Lakes prevents navigation. Temporary

[9] Although in the past score of years the number of accidents has been greatly reduced in both branches of the iron-mining industry, the number of killed or injured per equivalent number of man-days or man-hours of exposure is approximately twice as large in underground mines as at open-pit mines. (See table A-17.)

[10] A large amount of overburden stripping, however, is normally conducted during the winter, despite the cold weather and difficulties resulting from freezing. Winter stripping avoids interference with regular mining operations and reduces the period of idleness of power shovels and haulage equipment as well as of workers.

suspensions of work, however, may occur even during the summer because of unusual rains, cloudbursts, or floods.

Furthermore, the necessity of dumping overburden on nonmineral land or on ground overlying deposits that are too far below the surface for possible open-pit mining sometimes involves difficult problems and may entail moving waste materials long distances from pits. Underground mines in the Lake Superior District that customarily operate during the winter must also have space for their ore stock piles; these piles, however, are temporary and comparatively small.[11]

Finally, mining by the open-pit method necessitates the removal of all material in the pit overlying the ore, whereas this is not necessary in underground mining. In order to mine the ore in an open pit it is necessary to remove not only the glacial drift covering the ore body but also layers of taconite,[12] lean ore, or paint rock, and materials within the ore body which are either waste or very lean in iron. Occasional "horses" of taconite jutting up into the ore body may sometimes be avoided by mining around them, and some of the ore at the sides or bottom of the pit mixed too much with waste may be left; but foreign materials or lean ore in the form of horizontal layers separating layers of good ore must be removed. It is estimated that 10 percent or more of a typical open-pit ore body on the Mesabi range consists (after removal of overburden) of these nonmerchantable materials that must be removed in the course of mining.[13] In underground mines, when quantities of rock or unsalable ore are met, they can often be left in place by mining around them.

On the other hand, the necessity of removing all material encountered in open-pit mining assures complete recovery of high-grade ore because every dipperful comes within view of the shovel engineer. In the past quarter-century even the nonmerchantable ore from open pits, too lean to concentrate profitably by present methods, was stock-piled and is available for possible future use. The loss of ore even in good underground mining in the early days of the Mesabi range was from 10 to 20 percent,[14] and in some old underground workings later mined by open-pit methods, as much as 40 percent of the ore had been left in the mine.[15]

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[11] Stock-piling and subsequent removal of ore from stock piles at underground mines are a small but additional factor in the higher labor requirements of these mines.

[12] Cherty or jaspery, but at times calcareous or more or less quartzitic rock that incloses the soft hematites of the Mesabi range. It is sometimes referred to as jasper or iron formation.

[13] In estimating tonnages on the Michigan ranges and on the Cuyuna range, it is customary to deduct 10 percent of the estimated tonnage for rock inclusions in the ore body. See *The Iron Ores of Lake Superior* (7th ed.; Cleveland, Ohio: Crowell & Murray, 1930), p. 40.

Footnotes 14 and 15 appear on following page.

OUTSTANDING FACTORS IN THE GROWTH OF OPEN-PIT MINING

Iron mining in the United States, from its beginnings in the early Colonial period[16] to the opening of the Mesabi range in 1892, began in all the older districts with open-pit excavations (or open cuts on hillsides) at points where the easily discovered ore outcropped at the surface; as the deposits at or near the surface were exhausted, it became necessary to resort to underground methods. With few exceptions, such as the Cornwall deposits of Lebanon County, Pennsylvania, which have been mined by open-pit methods for the past 200 years,[17] the amount of ore near the surface was limited, and the extension of underground mining was retarded because of the crude and costly mining methods of the time. Until about 1870–80 most of the iron ore in all districts, except possibly New Jersey and New York, was extracted from open-pit or open-cut excavations.[18] Iron ore was intermittently mined on a small scale with crude hand methods from many scattered outcrops and was sent, often by team, to nearby smelting furnaces.

Open-pit mining in the Lake Superior District began in 1846 on the Marquette range in Michigan. Most of the operations prior to 1860 consisted merely of gathering loose masses of iron ore that were scattered about on the surface. When loose outcrops were no longer available, the hard ores were mined with the aid of hand drills and black powder until about 1880. By this time the pits had become so deep that the removal of thicker overburden became unprofitable and it was cheaper to mine by underground methods.[19] The first shipments of iron ore from the

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[14] F. W. Denton, "Open-Pit Mining, With Special Reference to the Mesabi Range," *Proceedings of the Lake Superior Mining Institute*, Vol. III (1895), p. 92.

[15] Albert H. Fay, "Steam Shovel Work on Mesabi Range," *The Engineering and Mining Journal*, Vol. XCI (Feb. 25, 1911), p. 423.

In referring to open-pit mining of the Tilly Foster iron mine in New York in 1887, Mr. R. W. Raymond made the following interesting comment: "The advantage of tearing down a hanging-wall in broad daylight, taking everything as it comes, and feeling sure that we have got it all, is no small satisfaction, and deserves to be considered as one of the favorable features of the stripping system." See discussion (p. 638) of an article by F. H. McDowell, "Stripping Ore-Deposits," *Transactions, A.I.M.E.*, Vol. XVIII (1890).

[16] Iron ore was first mined in the early part of 1608, and in the same year about 35 tons were exported from Jamestown, Massachusetts Bay Colony, to England. See William B. Phillips, "Iron and Steel," *Mineral Industry: 1892* (New York: The Scientific Publishing Co., 1893), I, 271.

[17] Since 1740; J. P. Lesley and E. V. d'Invilliers, "Report on the Cornwall Iron Ore Mines, Lebanon County," *Annual Report of the Geological Survey of Pennsylvania for 1885* (Harrisburg, Pa.: Board of Commissioners for the Geological Survey, 1886), p. 562.

[18] Major T. B. Brooks, "Iron Bearing Rocks (Economic)," *Geological Survey of Michigan: Upper Peninsula, 1869–1873* (New York: Julius Bien, 1873), vol. I, pt. I, p. 244. See also the *Tenth Census of the United States: 1880*, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), pp. 78–455. See also James F. Lewis, "The Hematite Ore Mines and Blast Furnaces East of the Hudson River," *Transactions, A.I.M.E.*, Vol. V, 1876–77), pp. 216–35.

[19] S. R. Elliott, J. E. Jopling, and Others, "Mining Methods of Marquette District, Michigan," *Transactions, A.I.M.E.*, Vol. LXXII (1925), p. 126.

Menominee range in 1877 and from the Gogebic and Vermilion ranges in 1884 were also from open pits.[20] Today none of the ore of the Vermilion range - and but a small proportion of that mined on the Marquette, Menominee, and Gogebic ranges - is produced from open-pit operations.

In the Birmingham District of Alabama, where iron ore was produced before the Civil War, none was mined underground until 1875;[21] in the past decade about 90 percent of the total output of merchantable ore was from underground operations. (See table A-6.)

Thus all or almost all the first iron ore in each newly discovered district was mined by open-pit methods. With few exceptions, the amount of ore available for open-pit mining was very limited because usually only a small part of the ore body in the steeply pitching iron formations was near the surface and because the thickness of overburden that could be removed with the existent techniques was relatively small. It was not long after the opening of all the early districts, where iron mining has persisted to the present day, before underground methods became the chief means of continued ore extraction.

With the discovery and exploitation (beginning in 1892) of the Mesabi range in Minnesota, open-pit mining received a new impetus. Here the enormous deposits were unusually well adapted for open-pit mining on a large scale. The huge ore bodies are almost flat-lying and near the surface. (See figure 17.) Both the overburden (consisting of clay, sand, gravel, and a few granite boulders) and the soft ore are easily excavated by mass methods employing powerful machinery.[22] Mining companies quickly took advantage of the favorable natural conditions, and as previously observed, the development of the Mesabi range in the first two decades after its opening was exceedingly rapid. After 1912 the Mesabi share of the total iron-ore production leveled off at about 55 to 60 percent, and the main effect of the growth of iron mining in this

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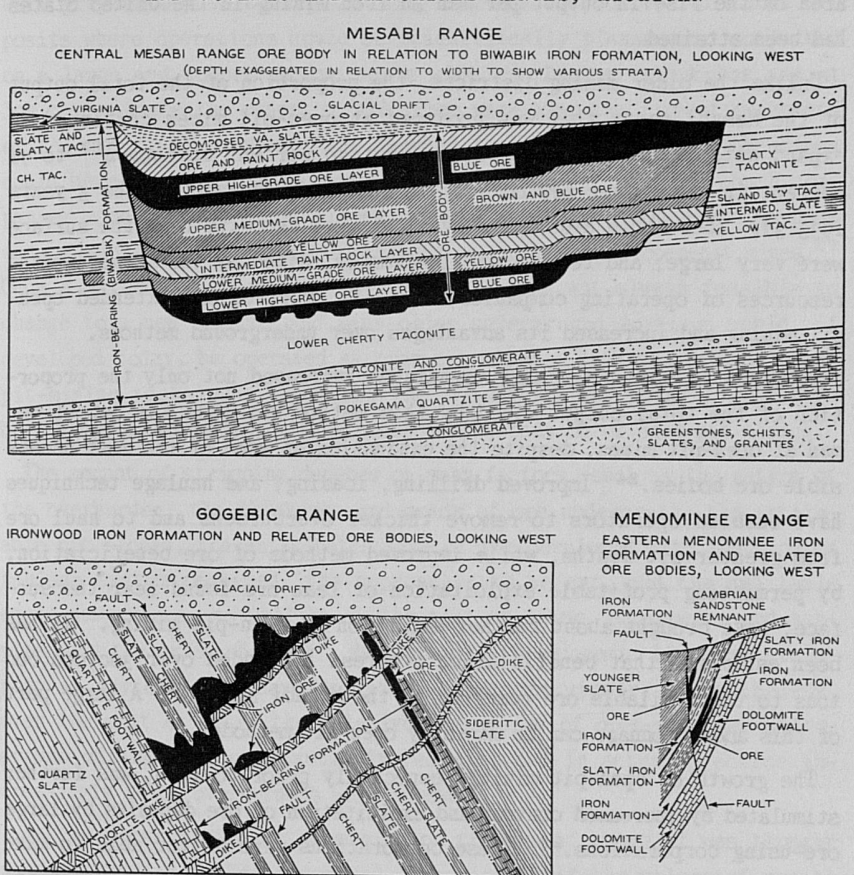
[20] John Fulton, "Methods of Mining in the Menominee Range, Michigan," *Transactions, A.I.M.E.*, Vol. XVI (1887-88), pp. 891-905; also John Birkinbine, "The Resources of the Lake Superior Region," *Transactions, A.I.M.E.*, Vol. XVI (1887-88), pp. 172-88.

[21] W. R. Crane, *Iron-Ore (Hematite) Mining Practice in the Birmingham District, Ala.* (U. S. Dept. Com., Bur. Mines, Bull. No. 239, 1926), p. 3.

[22] As aptly stated by H. V. Winchell and J. T. Jones in 1893:

"In the history of mining in this country there has been nothing exactly similar to the Mesabi iron-range in Minnesota, and the conditions there prevalent. Soft-ore mines are found in many parts of the country. In some the deposits are vertical, and are worked in open pits, or have been so worked, until it was found cheaper to go under ground. In other localities, the ore is scattered through clay beds in the form of hard lumps. These clay beds are sometimes excavated in open pits, and the ore separated by washing. On the Mesabi, the ore itself occurs in strata, and these strata appear quite flat to one standing upon the ground. The ore is soft in the main, and does not require much sorting to free it from foreign or deleterious substances. It is usually covered by the glacial drift-mantle, but occasionally passes beneath a capping of jasperoid rock called 'taconite.' The ore is twice or three times the thickness of the layer of drift lying upon it." "The Biwabik Mine," *Transactions, A.I.M.E.*, Vol. XXI (1892-93), p. 951.

Figure 17.- TYPICAL CROSS SECTIONS OF MESABI RANGE, MINNESOTA, AND GOGEBIC AND MENOMINEE RANGES, MICHIGAN



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Most of the ore deposits on the Mesabi range lie under a cover of glacial drift of varying thickness, rarely under rock capping. The deposits of soft ore, usually of large horizontal dimensions, are nearly flat - dipping at an angle of only about 8 or 10 degrees from the horizontal. Thus a large proportion of the ore is near the surface and accessible to inexpensive mining by open-pit methods.

In other districts the iron formations are inclined at steeper angles, and some are much folded and faulted. For example, the iron formation on the Gogebic range dips at an angle of from 45 to 75 degrees, and on the Menominee range from 15 to 90 degrees. Only a small proportion of the ore in iron formations such as these can be mined by open-pit methods. Continued mining by following the ore bodies from their outcrops soon becomes uneconomical if not impossible, since it necessitates removal of a rapidly increasing amount of hard overburden in relation to the quantity of ore uncovered. In order to maintain pit slopes that will not cave or slide, it is necessary to remove not only the overburden lying directly above the ore body but also that lying outward from it. An inverted cone or wedge must be excavated, of which only the apex is ore. If the ore body is far below the surface, the amount of overburden to be removed to reach the ore would be very large.

The diagrams for the Mesabi and Gogebic ranges were adapted from *U. S. Steel News*, Vol. 2, No. 6 (June 1937), inside cover; for Menominee range, from Stephen Royce, "Geology of the Iron Ranges," *Lake Superior Iron Ores: 1938* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), p. 37.

area on the rise in output per man in iron mining in the United States had been attained.

Unlike the older mining districts, the proportion of the total output of the Mesabi range that was produced at open-pit mines continued to expand with further mining - from about 50 percent in 1902-4[23] to 71 percent in the 5-year period 1915-19 and to 89 percent in the 5 years 1933-37. (See table A-6.) The available ore deposits near the surface were very large; and technological advances, aided by the large capital resources of operating companies, steadily improved and extended open-pit mining and increased its advantages over underground methods.

Progress in open-pit-mining techniques increased not only the proportion of the total output mined by this method but also the output per man at open-pit mines, despite the exhaustion of some of the most accessible ore bodies.[24] Improved drilling, loading, and haulage techniques have enabled operators to remove thicker overburdens and to haul ore from greater pit depths, while improved methods of ore beneficiation, by permitting profitable exploitation of lean ore found near the surface, have brought about further expansion of open-pit mining. It has been estimated that beneficiation progress has added over 300,000,000 tons to the available ore reserves on the Mesabi range.[25] A large part of this added tonnage can be mined by open-pit methods.

The growth of open-pit mining, especially prior to 1909, was further stimulated by increased control and exploitation of ore deposits by large ore-using corporations.[26] These corporations were better able to make the heavy initial investment required for exploration and development

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[23]Kirby Thomas, "Mining Methods in the Vermilion and Mesabi Districts," *Proceedings of the Lake Superior Mining Institute*, Vol. X (1904), pp. 151, 154; see also Dwight E. Woodbridge, "The Mesabi Iron-Ore Range - IV," *The Engineering and Mining Journal*, Vol. LXXIX (Feb. 9, 1905), p. 267. Mines using the milling method are included. In 1902 about 7 percent of the total Mesabi output was produced by milling.

[24]The nearness to the surface of the deposits on the Mesabi range has facilitated the early exploration of the entire range, and the size, quality, and location of the ore bodies have been well known from almost the very beginning of the development of the range. Some of the best ore bodies, underneath the thinnest overburden, were developed soon after the opening of the Mesabi range, and some of these have since been completely exhausted. The total amount of iron ore shipped from the Mesabi range up to the end of 1937 was 1,031,200,000 gross tons, about 70 percent of which was mined from open pits. About 5.2 percent of the total shipments was produced from mines now exhausted or abandoned, and an additional 2.5 percent from mines that have not shipped since 1910 although they are not considered exhausted. From 42 to 45 million tons of ore were shipped from open-pit mines that are either exhausted or have not shipped since 1910. See *Lake Superior Iron Ores: 1938* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), pp. 202-51.

[25]Kenneth Leith and Donald M. Liddell, *The Mineral Reserves of the United States and Its Capacity for Production* (National Resources Committee, mimeo., Mar. 1936), pp. 98-9.

[26]By 1909 the U. S. Steel Corporation alone, through a subsidiary, mined and shipped 55 percent of the output from the Lake Superior District and controlled about 75 percent of the known ore reserves. See J. R. Finlay, "Cost of Pig Iron Made From Lake Superior Ores," *The Engineering and Mining Journal*, Vol. LXXXVII, No. 15 (Apr. 10, 1909), p. 739.

work preparatory to open-pit mining and for the control of large deposits where operations could be scientifically planned and conducted on a large and comprehensive scale with the latest techniques and at low cost. Since the owners of the mines were also the largest consumers of the ore mined, a market was assured for a long time, and the mines could be planned and developed from a long-range viewpoint. Such companies more frequently developed new ore deposits by open-pit methods and in many cases converted underground operations into open-pit mines.[27] Once a method has been chosen, however, it is not always feasible to change to a new method, and many older underground workings would, if developed today, be operated as open-pit mines. With progress in open-pit-mining techniques, however, the economical stripping limits have been steadily extended, with a consequent expansion of open-pit mining.

The amount of stripping depends on many factors, such as the nature of the overburden, the thickness and grade of ore underneath, the attainable pit slopes, the anticipated size of the developed pit, the kind of haulage system required, the approaches to be cut, and the available waste-dump space, as well as on the cost of labor, equipment, and supplies and the price of ore.[28] As a result, the economic limits of stripping at any one time have differed, sometimes widely. Nevertheless, over the past 45 years the relative advantages of open-pit over underground mining were constantly increasing, and in actual practice increasingly thick overburdens were removed.

In the first few years of mining on the Mesabi range it was thought that overburden could be removed economically if the volume of ore to be recovered was equal to or greater than the volume of stripping and if the total depth of the overburden did not exceed 35 or 40 feet.[29] This is somewhat less than about 1 foot in depth of overburden to each foot in depth of ore, since some overburden must be removed without uncovering ore to allow for pit approaches, berm, and pit wall slopes. In practice, however, overburden stripping was not undertaken in the first 5 years of mining on the Mesabi range unless there were at least

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[27] These include many of the largest open-pit mines on the Mesabi range, such as: Hull-Rust, Sellers, Burt-Pool-Day, Susquehanna, Albany, Minnewas, Corsica, Scranton, Hoadley, and others. See *Lake Superior Iron Ores: 1938*, pp. 202-51. See also Fay, *op. cit.*, pp. 420-3.

[28] The decision in favor of the open-pit method may sometimes turn on some circumstance that increased the relative cost of mining by underground methods. Thus it was stated in 1905 that the trend toward deeper stripping and the removal of more overburden per ton of ore was influenced not only by the availability of larger and more economical open-pit machinery but also by an increase in the cost of timber and higher wages. These developments increased the relative costs at underground mines which required much more timber and labor than open-pit operations. See Woodbridge, *loc. cit.*

[29] Per Larsson, "Soft Ore Mining on Lake Superior," *Proceedings of the Lake Superior Mining Institute*, Vol. I (1893), pp. 14 ff. See also Denton, *loc. cit.* and Woodbridge, *loc. cit.*

2 feet of ore to 1 foot of surface.[30] As late as 1904, the removal of even 1 foot of overburden for each foot of ore was considered impracticable, as was the stripping of overburden over 50 to 60 feet thick.[31]

In the next decade the ideas as to the permissible depth in stripping overburden changed radically. Stripping of 80- to 90-foot glacial drift was undertaken in 1905, and plans were being considered for removing much heavier overburden.[32] In 1907 Dwight E. Woodbridge suggested that it was profitable to strip 3 or 4 feet of overburden for each foot of ore,[33] and in 1909 J. R. Finlay concluded that it would pay to remove 2 tons of overburden to 1 ton of ore under the least favorable mining conditions, and that under the most favorable conditions, where both the ore and the overburden were soft and uniform, the economical proportion may rise as high as 4 or even 5 to 1.[34] In volume this represents a ratio of from 4 to 1 to 8 or 10 to 1. These last two estimates may have been too high in view of what apparently were more careful estimates made later by Charles van Barneveld and others. In 1910 work was begun near Hibbing for the removal of overburden 120 feet thick,[35] and in 1911 the average thickness of surface stripped from a part of the Buffalo and Susquehanna mine was 147 feet.[36] About this time the economical limit of stripping on the Mesabi range was generally considered to be reached with:[37]

1. The ultimate removal of not more than 1 cubic yard of overburden for each ton of ore.

2. A depth ratio of overburden to ore not greater than 2, if the overburden consisted of ordinary glacial drift. If hard slates or taconite

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[30] C. E. Bailey, "Mining Methods on the Mesabi Range," *Transactions, A.I.M.E.*, Vol. XXVII (1897), pp. 530-1. See also Winchell, *loc. cit.*

[31] Thomas, *op. cit.*, p. 151.

[32] Woodbridge, *op. cit.*, p. 268.

[33] Dwight E. Woodbridge, "Lake Superior Iron Mines in 1907," *The Engineering and Mining Journal*, Vol. LXXXV, No. 2 (Jan. 11, 1908), p. 115.

[34] Finlay, *op. cit.*, p. 743.

[35] Dwight E. Woodbridge, "Notes From the Lake Superior Iron Ranges," *The Engineering and Mining Journal*, Vol. 89, No. 17 (Apr. 23, 1910), p. 863.

[36] Fay, *op. cit.*, p. 423.

Costs of stripping vary, of course, with operating conditions, being one-fourth to one-fifth higher in winter than in summer; two or three times higher in the removal of hard materials, such as solid taconite and hard slates which require blasting, than in stripping ordinary glacial drift; higher for small jobs than for large jobs, etc. Contract prices for removal of ordinary glacial drift by steam shovel, with similar operating conditions, declined at least one-fourth between 1894 and 1911 - from 30 to 50 cents per cubic yard in 1894 to from 25 to 35 cents in 1911. Most of the stripping work at this time was done by contractors. See J. Parke Channing, "Lake Superior Iron Ore," *Mineral Industry: 1894* (New York: The Scientific Publishing Co., 1895), III, 396; Edgar K. Soper, "The Iron Ranges of Minnesota," *The Engineering and Mining Journal*, Vol. XCI (Apr. 15, 1911), p. 769; and Woodbridge, "The Mesabi Iron-Ore Range - IV," pp. 266-7.

[37] See van Barneveld, *op. cit.*, p. 45. See also Willard Bayliss, E. D. M'Neil, and J. S. Lutes, "Mining Methods on the Missabe Iron Range," *Proceedings of the Lake Superior Mining Institute*, Vol. XVIII (1913), p. 135.

were encountered, each foot of such material was considered to be equivalent to 3 feet of ordinary overburden.

3. A maximum stripping depth, under any considerations, of 150 feet.

By 1928, if an ore deposit could be mined by open-pit methods without necessitating removal of more than 3 cubic yards of waste material for each ton of ore made available, it was considered within the economic limits of open-pit mining.[38] Ten years later, stripping operations at the Hill-Annex mine at Calumet, Minnesota, were carried on to a depth of 240 feet - thicker overburden than had ever been removed before on the Mesabi range.[39]

RISE IN OUTPUT PER MAN AT OPEN-PIT MINES

Although the long-time trend of labor productivity at open-pit mines is definitely upward, the year-to-year changes were sometimes marked by wide fluctuations. Thus, between 1915 and 1938, for which separate data for open-pit operations are available, output per man-hour declined during the World War period,[40] and in years like 1921, 1924, 1927, 1930-32, and 1938 when the total output of iron ore was greatly reduced. (See figure 18.) These interruptions to the general rise in man-hour output were more or less temporary in character and are primarily accounted for by increases in the amount of overburden removed in relation to the quantity of ore mined; by decreases in the proportion of capacity utilized (as roughly indicated by declines in production)[41] and hence in the effectiveness of machinery and labor employed; and in 1932 by a sharp rise in the proportion of merchantable ore produced that was concentrated.[42]

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[38] 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* (U. S. Dept. Com., Bur. Mines, Bull. No. 298, 1929), p. 218.

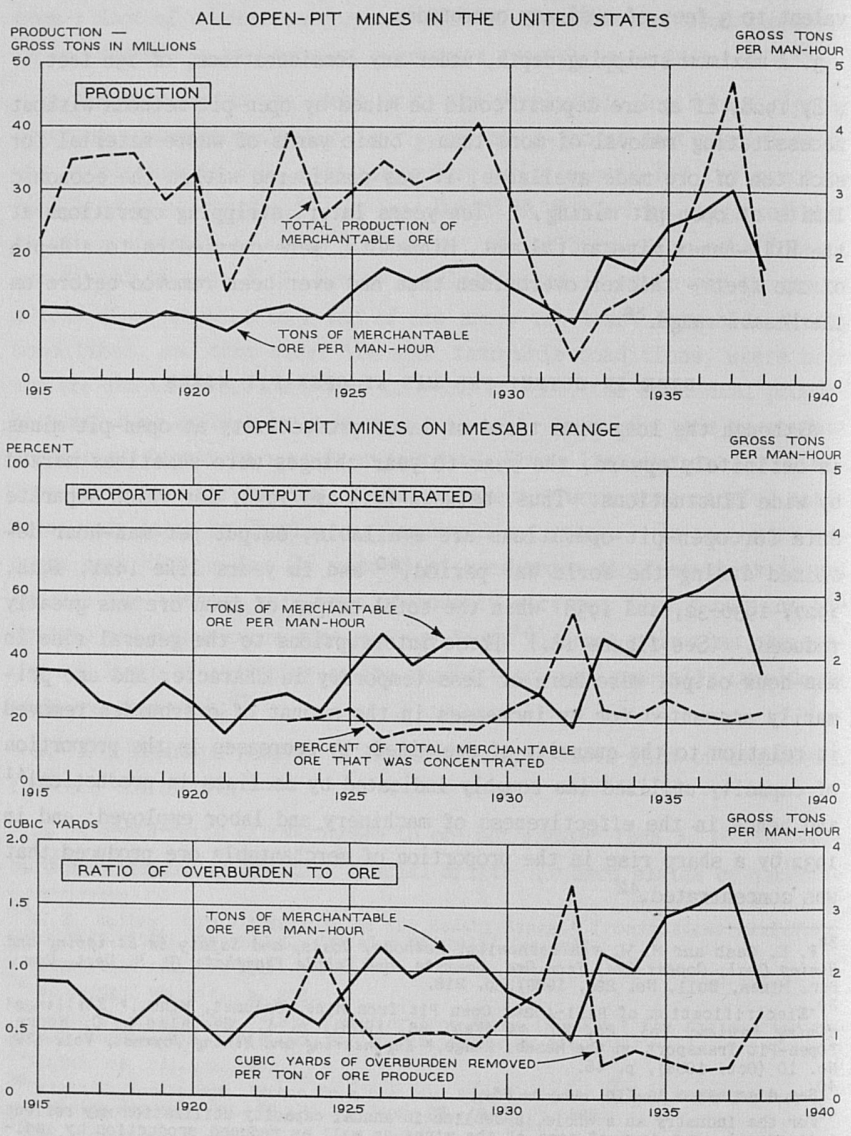
[39] "Electrification of Hill-Annex Open Pit Iron Mine, Calumet, Minn.," *Skillings' Mining Review*, Vol. 26, No. 44 (Feb. 26, 1938), p. 1. See also L. C. Moore, "Open-Pit Transport on the Mesabi Range," *Engineering and Mining Journal*, Vol. 139, No. 10 (Oct. 1938), p. 45.

[40] See discussion in ftn. 44, p. 66.

[41] For the industry as a whole, a decline in annual capacity utilization may reflect a temporary shut-down of some of the mines as well as reduced production by individual mines owing to the closing of some portions of them or to the operating of a fewer number of shifts per day or per year. If a decline in the percentage of capacity utilized had resulted only from a reduction in the number of mines in operation, possibly reflecting a decrease in the number of the less efficient mines active, the result might have been an increase rather than a reduction in output per man. The kind of decline in capacity utilization that has reduced output per man was that which resulted from a reduced scale of operations on the part of mines continuing to produce ore. That such a reduction has actually occurred was indicated indirectly by data in fig. 5, ch. III, where it was shown that output per mine-shift of producing mines only had declined in depression periods. Data for a direct measure of changes in the percentage of ore-mining capacity utilized are not available.

[42] It should be noted that output per man-hour considered in this report is the ratio between the quantity of merchantable ore produced and man-hours worked by all wage earners at the mines, including those engaged in overburden stripping (even though employed by contractors) and in concentration of lean ore, as well as those engaged in excavating ore.

Figure 18.- CHANGES IN MAN-HOUR OUTPUT COMPARED WITH CHANGES IN PRODUCTION, IN PROPORTION OF OUTPUT CONCENTRATED, AND IN THE OVERBURDEN-TO-ORE RATIO AT OPEN-PIT IRON MINES, 1915-38



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Although the general trend of output per man at open-pit mines since the World War has been upward, the year-to-year changes have exhibited wide fluctuations. This was due in part to variations in mining capacity utilized as roughly indicated by changes in production, in part to fluctuations in the proportion of the product that was concentrated at the mines, and in large part to changes in the amount of overburden removed in relation to the quantity of ore produced. For example, during the depression, especially in 1932, man-hour output of merchantable ore dropped to a very low point because the mines were operating at a greatly reduced rate and were consequently unable to make most effective use of labor and machinery; because of the increase in the proportion of lean ore mined and the necessity for additional labor to concentrate it; and because of an increase in the amount of overburden removed per ton of merchantable ore produced (with a corresponding increase in the proportion of the labor force that was engaged in stripping). (See tables A-6 and A-19 for data.)

The influence of these factors was offset to some extent by others that tended to raise output per man. Among these were: Labor economies on the part of some operators whereby the work loads of employees were increased and the most efficient workmen were retained while others were laid off; cessation of operations by some of the less productive mines; and production of a larger proportion of the more accessible or richest ore (not requiring concentration). These were not the predominant factors on the Mesabi range, however, and the average output per worker at open-pit mines in the United States is dominated by the average for the Mesabi range, which produces more than 85 percent of the total open-pit output.

As far back as the record of labor productivity at open-pit mines is available, each business depression is clearly marked by a drop in output per man. During such periods fewer mines were in operation, and it may be presumed that the ones continuing to produce ore were normally more efficient, although with a reduced scale of operations conditions were not conducive to a maximum man-hour output. But what is more important in its influence on average output per worker is that the mines curtailed their production to a larger extent than they reduced their development work in preparation for future mining. Production at less than full capacity in itself retards output per man insofar as the labor force is not cut in the same proportion as production is diminished. Although manned with the same number of men in the crews, the loading, hauling, and other machinery performs only a part of the work it is capable of doing, and much labor time is spent in getting ready to work or in idle waiting.

Output per man was reduced even more by a rise in the number of cubic yards of overburden removed per ton of ore produced; for the removal of a ton of overburden, which weighs about one-half as much for the same volume as ore, probably requires as much - if not more - labor as the mining of a ton of ore. For example, open-pit production on the Mesabi range was greatly curtailed in 1924 and during the depression in 1931-36, but quantity of overburden removed in 1924 increased above that of the preceding year, and, although it declined during the great depression, production of ore declined more. As a result, the quantity of overburden removed per ton of ore produced, which averaged 0.52 cubic yard during the 16-year period 1923-38, reached a peak of 1.15 cubic yards in 1924 and 1.68 cubic yards in 1932. (See figure 18 and table A-19.) On the other hand, the output of merchantable ore per man-hour dropped to the lowest points in these years and in other years varied

inversely to the quantity of overburden removed per ton of ore produced.[43] The extremely low point reached in output per man in 1932 is further accounted for by a large increase in the proportion of the total merchantable ore produced that had to be concentrated before shipment. During 1923-38, 21 percent of the total merchantable ore produced on the Mesabi range was concentrated; the proportion rose to 54 percent in 1932. (See figure 18.) However, when output per man-hour is expressed in tonnage of all material removed (including the overburden removed and both the direct-shipping ore and that requiring concentration), the man-hour output shows a more continuous increase. (See the lower segment of figure 19.)

Over the 23-year period 1915-37 the average output of merchantable ore per man-hour at open-pit iron mines in the United States increased 224 percent as compared with 114 percent at underground mines. Since output per man is about three times as large at open-pit mines as at underground operations, the rise at the former represents a much larger increase in actual tonnage. Thus, although the average annual increase in tons per man-hour was 0.016 at underground mines, it was 0.071 at open pits, or more than four times as large.[44]

During 1915-37 the average annual increase in output per man-hour at open-pit mines on the Mesabi range, which produce more than 85 percent of the total open-pit output, was 0.066 gross ton, and the 22-year increase of 1.452 gross tons represented an advance of 135 percent. At open pits elsewhere, man-hour output had increased 442 percent during the same period. However, since the average output per man was about one-third that of pits on the Mesabi range, the absolute increase in tons per man-hour represented by this percentage rise was smaller - amounting to 0.990 gross ton over the 22 years, or an average annual advance of 0.045 gross ton.

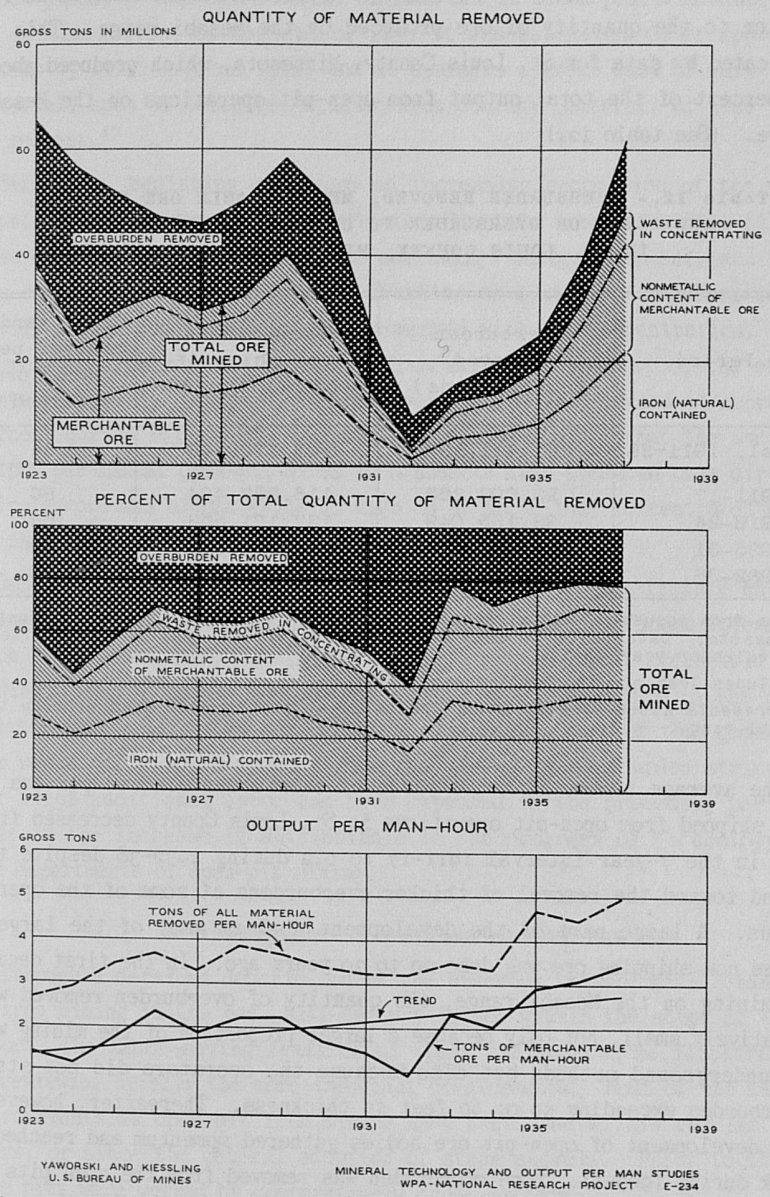
During the period covered by the analysis, 1915-38, one of the contributing long-time factors that raised the output per man at open-pit

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[43] The relative increase in development work, reflected in an increase in the number of cubic yards of overburden removed per ton of ore produced and in a lower output per man, was confined largely to the open-pit mines on the Mesabi range. Output per man at open-pit mines elsewhere increased both in 1924 and 1932.

[44] The tons-per-man-hour figures on which these percentage and tonnage increases are based were computed from the trend values of data in table A-6, the straight-line trend being computed by the method of least squares. This procedure was followed in preference to using the raw data for the initial and terminal years of the period considered, since it served largely to distribute more evenly the influence of unusual temporary fluctuations in the volume of production and development work that have a large effect on output per man. For example, the actual output per man-hour at open-pit mines in 1937 was 3.00 gross tons, but the production rate was unusually high and the relative amount of overburden removed was unusually low; hence the output per man-hour under more normal conditions would have been lower. The computed trend value for 1937 was 2.26 tons per man-hour. (See also ftn. 12, p. 12.)

Figure 19.- OVERBURDEN AND ORE REMOVED AND OUTPUT PER MAN-HOUR AT OPEN-PIT MINES ON THE MESABI RANGE, MINNESOTA, 1923-37



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The total quantity of material removed from open-pit operations is much larger than the quantity of merchantable ore produced, and changes in the amount of this material handled from year to year greatly influence output per man. On the Mesabi range, during 1923-37 for example, although the quantity of overburden removed was usually less than the amount of ore produced, the former occasionally exceeded the latter, as in 1924 and in 1932; and the effect was a greatly reduced output of merchantable ore per man-hour. Much less important than overburden, but gradually increasing, is the amount of waste contained in lean crude ore mined and later removed at the mines to obtain a merchantable product. When output per man-hour is expressed in terms of all material removed (reduced to a weight basis), the amplitude of its fluctuations is smaller than those of the output of merchantable ore per man-hour. (See tables A-6 and A-19 for data.)

mines was a gradually decreasing quantity of overburden removal in relation to the quantity of ore produced on the Mesabi range. This is indicated by data for St. Louis County, Minnesota, which produced about 75 percent of the total output from open-pit operations on the Mesabi range. (See table 12.)

Table 12.- OVERBURDEN REMOVED, MERCHANTABLE ORE SHIPPED, AND RATIO OF OVERBURDEN TO ORE AT OPEN-PIT MINES IN ST. LOUIS COUNTY, MINNESOTA, 1911-38[a]

Period	Overburden removed[b] (cubic yards)	Merchantable ore shipped[c] (gross tons)	Cubic yards removed per ton of ore shipped
Total, 1911-38	261,411,137	483,179,240	0.54
1911-17	93,608,265	116,867,494	.80
1918-24	93,155,049	137,171,553	.68
1925-31	56,936,615	141,953,541	.40
1932-38	17,711,208	87,186,652	.20

[a]Data from issues of *Annual Report of Inspector of Mines, St. Louis County, Minnesota.* Data prior to 1923 are for years ending June 30; thereafter, for calendar years.

[b]Excludes lean ore stock-piled separately.

[c]Represents about 75 percent of the total shipments from open pits on the Mesabi range.

The average number of cubic yards of overburden removed per ton of ore shipped from open-pit operations in St. Louis County decreased from 0.8 in the 7-year interval 1911-17 to 0.2 during 1932-38 despite the trend toward the removal of thicker overburdens at some of the operations. A large part of the development work at many of the largest mines now shipping ore was done 20 to 30 years ago. In the first decade of mining on the Mesabi range, the quantity of overburden removed was relatively small, not only because a larger proportion of the mining was by underground methods but also because the operators did not strip overburden exceeding 50 or 60 feet in thickness. Thereafter, however, the development of open-pit ore bodies gathered momentum and reached a peak during 1909-11. More overburden was removed from the open pits of St. Louis County in the 12 months ended June 30, 1911, than in any other year in the history of mining in this county, and the number of men engaged in stripping exceeded the number in open-pit ore mining.[45]

Since about 1910, however, the influence of decreased stripping has been offset in part by a growth in the amount of lean ore mined and

[45]See *Annual Report of Inspector of Mines, St. Louis County, Minnesota for the Year Ending June 30, 1911* and similar reports for other years.

stock-piled.[46] The exact amount of lean ore in stock piles in Minnesota is not known, but by the end of 1937 it was estimated to be approximately 75 million gross tons, and it contains a great deal of very lean material, such as taconite, with an iron content (natural) of less than 36 percent.[47]

Similarly, beginning with 1907 an increasing proportion of the merchantable ore produced at open-pit mines has been concentrated or otherwise beneficiated (by crushing or screening) before shipment, and this has required additional labor. Crushing or screening requires relatively little additional labor as compared with ore concentration. The proportion concentrated increased from about 0.2 percent of the shipments in 1909 to 15 percent in the 5-year period 1915-19 and to about 25 percent during 1933-37.[48] It has already been noted[49] that the average output per man at open-pit mines in Minnesota that produced only direct-shipping ore was almost twice as high as at those that concentrated most of their product.

Despite the necessity to concentrate or otherwise beneficiate an increasing proportion of the product and despite other handicaps attendant upon the gradual depletion of the highest grade and most accessible ore bodies, average output per worker at open-pit iron mines in the past quarter-century has more than tripled. Although a part of this gain was the result of a decline in the relative amount of overburden stripping for which additional labor had been expended in the preceding period, most of the increase is attributable to the progress of technology in all departments of open-pit mining.

ROLE OF TECHNOLOGY IN RAISING OUTPUT PER MAN

Although a detailed description of the numerous technological changes in iron mining in the past half-century is not within the scope of this report, the labor-saving features of these changes can be illustrated by reviewing briefly the more important developments. Most of the major improvements in open-pit iron mining have been made within the last 50 years, or since the general adoption of steam shovels. Prior to this, open pits were worked by comparatively crude methods.

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[46] Measures of man-hour output in this study include the production of merchantable ore only.

[47] Estimate supplied through the courtesy of C. J. O'Connell, Iron Ore Division, Minnesota Tax Commission.

[48] Derived from data on quantities of concentrated and total ore shipped from Minnesota mines, as published in John J. Craig, *Mining Directory of Minnesota, 1938*, Vol. XLI, No. 30 (Univ. of Minn., School of Mines Expt. Sta., May 1, 1938), p. 204; and from data on amounts produced by open-pit mines as indicated in table A-6. It was assumed that practically all the concentrated ore came from open-pit operations.

[49] See p. 27 and table A-9.

Earlier Mining Methods

Before the general adoption of diamond drilling for work in hard materials in the late 1870's and early 1880's[50] and of prospect churn drilling in certain types of soft materials in the early 1890's, exploratory work was limited to seeking surface outcrops and to exploring such regions below the surface or in the sides of hills as could be reached by shallow test pits or drifts dug out with hand tools.

Blastholes in rock or hard ore were drilled by means of hand-held drill steels struck with sledge hammers. After the holes had been filled with explosives and blasted, the large chunks remaining were broken either with the use of picks, sledges, and wedges or by blockholing, whereby small holes were hand-drilled and blasted. A considerable amount of hand sledging was necessary, not only to break up the big chunks into sizes that could be lifted by the men but also to permit the hand sorting of waste rock in the ore. In many of the early open pits, such as those on the Marquette range in Michigan, large piles of ore and waste rock were constantly in the way of the workmen and sometimes had to be moved as frequently as three times before they were finally removed from the pit. Although power drills driven by steam or compressed air were used experimentally in the early 1870's[51] and introduced permanently in an operation on the Marquette range in 1878[52] and at the Cornwall mine in Pennsylvania in 1882,[53] they were not generally adopted until after 1890. Until the introduction of nitroglycerin and dynamite in the 1870's and 1880's[54] the only explosive used was slow-acting black powder.

The early loading methods were of the simplest kind; the broken material was hand-shoveled or simply picked up by hand and loaded into buckets or vehicles. In some of the deeper excavations on the Marquette range and in the Eastern States, hand-loaded buckets were slowly hoisted out of the pits by means of swing derricks and whims crudely resembling those commonly used today for unloading boats or in quarrying dimension stone. The long booms of these derricks made it possible to lower the bucket to different parts of a wide pit. At the swing-derrick operations in Michigan two men were required to fill the bucket, while one

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[50] Brooks, *op. cit.*, p. 259; see also Elliott, Jopling, and Others, *op. cit.*, p. 125.
[51] Brooks, *op. cit.*, p. 266.
[52] James E. Jopling, "The Marquette Range - Its Discovery, Development and Resources," *Transactions, A.I.M.E.*, Vol. XXVII (1897), p. 552.
[53] Lesley and d'Invilliers, *op. cit.*, p. 557.
[54] C. C. Cowpland, "A Resume of the Early History of the Explosives Industry in Marquette County," *Proceedings of the Lake Superior Mining Institute*, Vol. XXIX (1936), pp. 21-8.

man landed it and a driver with a team of horses operated the hoist.[55] At some of the earliest operations on the Mesabi range glacial drift was removed by means of horse-drawn, hand-guided scrapers, and as the area was heavily wooded, logging and brush cutting preceded the actual stripping operation.[56]

The earliest methods of haulage within the pit used carts or wheelbarrows pushed by manpower, and haulage from the pits was usually done with horse- or mule-drawn carts, wagons, or sleighs - often over rough, crooked, and steep roads. In some of the more advanced operations small wooden cars were set on narrow-gauge tracks and either pushed by men or pulled by animals. Iron ore was first hauled in cars on rails at

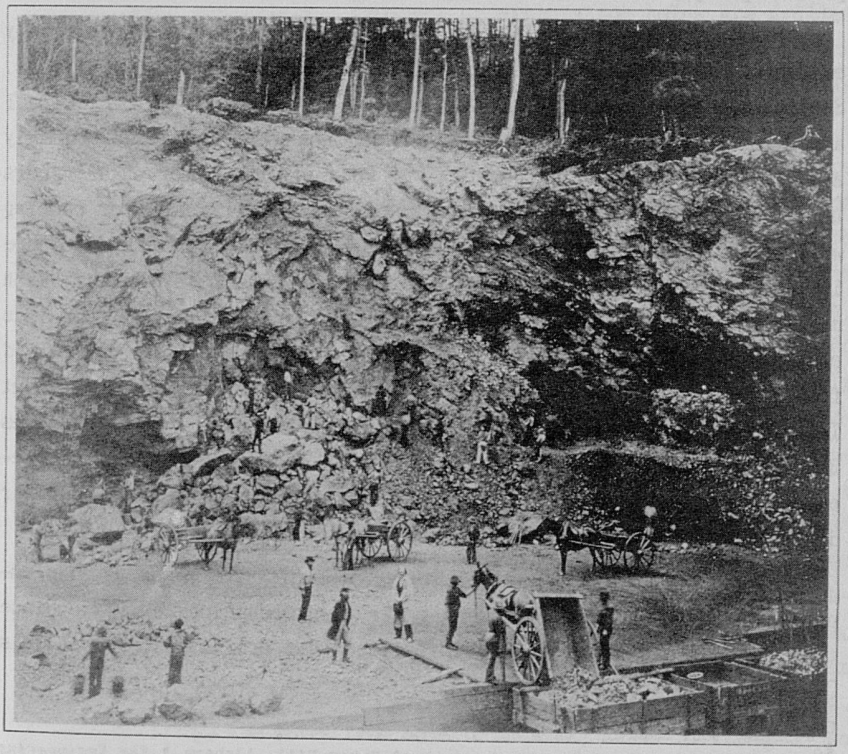


FIGURE 20.- OPEN-PIT MINING 80 YEARS AGO

This is a view of the Jackson mine, Negaunee, Michigan, in 1860 - before power shovels were used in open-pit iron mining. Ore was laboriously mined by hand with picks, sledge hammers, and hand shovels, then loaded into small two-wheel horse-drawn carts, and dumped into small wooden ore cars for haulage out of the pit on narrow-gauge track. At least 37 men are in this scene, although not all are visible in this reproduction.

[55] Brooks, *op. cit.*, p. 276.

[56] Larsson, *op. cit.*, p. 13; see also Dwight E. Woodbridge, "The Mesabi Iron Ore Range - I," *The Engineering and Mining Journal*, Vol. LXXIX (Jan. 12, 1905), p. 74.

the Cornwall mine in Pennsylvania in 1853[57] and a few years later at the Jackson mine in Michigan. (See figure 20.) Later, tunnels for railroad tracks were put in when practicable, and served both to avoid excessive grades and to reduce the amount of material that had to be removed in cutting pit approaches.[58]

Rope haulage was employed in some of the early excavations, and small cars or skips set on rails were pulled out of the pits over tramways or skip roads built on the slopes of banks. At some mining operations favorably located on hillsides, loaded cars were lowered on tracks built on inclines. In an ore bank in Alabama, ore was lowered from a hill on an inclined tramway on which the loaded tramcars, as they descended, pulled up empty ones.[59]

Mechanical power for haulage at open-pit operations was not generally employed until the beginning of the steam-shovel era in the 1890's. Small locomotives were used to haul cars as early as 1870 at the Cornwall and Jackson mines,[60] and small steam engines were also used - mostly at mines in New York, New Jersey, and Pennsylvania - for pulling cars up inclines, for hoisting the buckets of swing derricks, for pumping water, and for operating washers and crushers.[61] On the Marquette range in 1870, when the bulk of the ore was extracted from open pits, not much more than one-half of the total ore produced - and much less than this proportion of all the material - was handled by steam. Horses were used for the remaining tonnage, at a cost estimated at the time to be at least four times as much as that of power machinery.[62] About 32 mines used 364 horses and 12 hoisting and pumping engines of 10 to 50 horsepower; in addition, two 12-horsepower steam locomotives were used for distributing mine cars at the Jackson mine.

Thus, prior to the last half-century, open-pit iron mines usually employed much more human and animal power than mechanical energy. Since then, however, power drills have replaced hand drilling; power shovels

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[57] Lesley and d'Invilliers, *op. cit.*, p. 550.

[58] Jopling, *loc. cit.*

[59] Wm. M. Brewer, "The Brown Ore Deposit of Baker Hill, Alabama," *The Engineering and Mining Journal*, Vol. LV, No. 4 (Jan. 28, 1893), p. 77.

[60] Brooks, *op. cit.*, pp. 272, 281.

[61] The engines were small and crude; according to the census of 1870, there were a total of 315 steam engines at all iron mines in the United States, and they averaged 27 horsepower per engine. The 1880 census reported that 805 of the larger mines were using a total of 821 steam engines averaging 30 horsepower per unit; in addition there were about 4,000 horses and mules. The 1929 average was 233 horsepower per steam engine or turbine in use. See *Ninth Census of the United States: 1870*, "Wealth and Industry" (U. S. Dept. Int., Census Office, 1872), p. 760; *Tenth Census of the United States: 1880*, Vol. XV, "Report on the Mining Industries" (1886), p. 69; and *Fifteenth Census of the United States: 1930*, "Mines and Quarries: 1929" (U. S. Dept. Com., Bur. Census, 1933), p. 321; also Brooks, *op. cit.*, pp. 272, 274, 278; and Lewis, *loc. cit.*

[62] Brooks, *op. cit.*, p. 278.

or draglines have almost universally replaced hand loading; steam and electric locomotives, trucks, and belt conveyors have replaced hand tramming and animal haulage; and in many other respects improvements have been made in every process and detail of the iron-mining industry.[63] Although changes in several phases of mining have often occurred simultaneously and are closely related, for convenience of presentation they are here briefly considered under three broad functions, namely drilling and blasting, loading, and haulage and dumping.

Improvements in Drilling and Blasting[64]

Since output per man at iron mines was influenced by progress in two very distinct types of drilling - prospect and blasthole drilling - these are considered separately. Prospect or exploration holes are drilled for the purpose of obtaining information about ore bodies, whereas the object of blasthole drilling is to break or loosen ground and to facilitate its excavation.

For this reason the two types of drilling are very different. Since prospect drill holes are intended to reveal the presence and extent of ore bodies within the possible limits of future mining, the holes may be very long - sometimes in excess of 2,000 feet. Blastholes in open-pit iron mining are usually drilled only to the depth of the benches, which, although generally higher today than 25 years ago, rarely exceed 60 feet. In prospect drilling, cuttings from the hole must be carefully salvaged for assay purposes, and care must be taken to avoid contamination of the drill samples with foreign substances, such as metal particles rubbed off the drilling equipment or mixture of the sample for a given depth of hole with material from above. As a result, casing must often be driven into the hole so as to keep within a short distance of the bottom. The prospect driller is usually unfamiliar with the thickness and character of the formations through which he is drilling, so that he must "feel his way" and, consequently, operate more slowly than when blasthole-drilling through material already thoroughly explored. In blast drilling, the moves from hole to hole may be as little as 15 to 25 feet, whereas in prospect drilling they may be several hundred feet. Prospect drilling is often carried on in districts remote from settled

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[63] A number of small pits in Alabama, Georgia, and Missouri are still worked with picks, hand shovels, wheelbarrows, and carts or wagons. Such pits produced an aggregate of about 50,000 gross tons of merchantable ore in 1937.

[64] Much of the material incorporated in this section was originally prepared by Harry P. Sweeny, Consulting Mining Engineer of the WPA National Research Project. For a fuller review of progress in drilling in mining, see C. E. Nighman and O. E. Kiessling, *Mineral Technology and Output per Man Studies: Rock Drilling* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-11, Feb. 1940).

communities and sources of power and supplies. Repair shops may be a long distance away; water may be scarce; and roads may be very rough or absent altogether. In the early days of exploration in Minnesota, workmen encountered great difficulties in bringing their equipment and supplies to the points at which drilling operations were to begin. The area was thickly wooded and swampy, and much of the equipment and supplies had to be transported through the wilderness on the backs of men and animals.

Progress in Prospect Drilling.- Although progress in prospect drilling and exploration methods in general cannot be appraised quantitatively, it has had an important influence on the rise in output per man in the iron-mining industry in the United States. Not only has adequate prospecting revealed the presence of the largest, richest, and most accessible iron-ore deposits in the world, but it has also facilitated their economical exploitation. Prospect holes are drilled not only to prove the general location of ore bodies but also to determine the character and grade of ore in the various strata penetrated; to measure the size, shape, and contours of the ore bodies; and to indicate the nature and thickness of overburden covering them. This information and other data were necessary to enable the mine operator to decide whether the ore deposit, if exploitable, could best be worked by open-pit or underground methods and to plan the details of the general method chosen. The high output per man at many of the largest open-pit mines today is due in no small measure to the careful prospecting of their ore bodies, which was the basis of comprehensive and efficient development plans.[65]

Many of the earliest discoveries of iron-ore deposits were made at their outcrops, and a number of ore bodies in the Lake Superior District were discovered underneath the roots of fallen trees. The most promising exposures of ore were located early, however, and it was soon realized that most of the ore bodies were beneath a layer of glacial drift, if not under solid rock, and that it was necessary to explore below the surface. The effectiveness of prospect digging or drilling depended a great deal, of course, on knowledge of where to dig or bore. Naturally, many holes were dug near points where ore had been previously discovered. Later, with the aid of geologic maps and other knowledge

[65]Only in this indirect manner are improvements in prospect drilling reflected in our measures of output per man at iron mines. Since most of the labor involved in prospecting, especially in the early years of the Mesabi range, was employed by contractors specializing in this work and was not included in the U. S. Census reports of employment in the iron-mining industry, the reduced labor requirements in prospect drilling, resulting both from improved techniques and from the smaller amount of prospecting, are generally not indicated in the available measures of labor productivity.

gained from the studies and experience of miners, geologists, and engineers,[66] with the aid of the magnetic dip needle, and with improved drilling equipment, successful explorations were made farther afield. The most recent producing iron range - the Cuyuna range of Minnesota - was discovered solely through the use of the magnetic dip needle and subsequent prospect drilling at the "lines of attraction", for the iron formation does not come through the glacial drift at any point on this range.[67]

The earliest subsurface prospecting on the Mesabi range was generally limited to digging test pits with ordinary hand tools. These pits were just large enough to permit one man to dig with a pick and shovel and to load the loosened material into a bucket which was hoisted by a windlass operated by two men at the surface. Such early test pitting was usually abandoned at the water level since deeper digging would have involved costly water pumping.

If supplemented by deeper prospect drill holes, test pits are very useful, especially for gaining information about ore bodies after the discovery of their general location and perhaps after the overburden has been removed. They provide an ideal method for analyzing the ground penetrated, not only allowing a reliable chemical analysis of materials penetrated but also indicating the color and dip of the strata; and many open-pit operations still use them for ore sampling. Test pits alone, however, were inadequate because of their limited depth. Even on the Mesabi range, where the ore deposits are generally near the surface, it was necessary to explore down to a depth of 300 to 400 feet or more, whereas test pitting was limited to depths of not much more than 100 feet.[68] Many prospect holes were later drilled from the bottom of test pits, thereby greatly extending the depth explored.

The diamond drill, which penetrates rocks by a rotative cutting action and produces a core for inspection and assay, was the first power machine used for prospect drilling in the iron-mining industry.[69] First

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[66] It was said that field notes, taken as far back as 1892 by such men as J. Uno Sebenius, were used in charting boundary lines on the Mesabi range within which, by 1905, were found more than 90 percent of all the iron-ore deposits. See Dwight E. Woodbridge, "The Mesabi Iron Ore Range - II," *The Engineering and Mining Journal*, Vol. LXXIX (Jan. 19, 1905), p. 124.

[67] Holman I. Pearl, "A New Aid to Exploration in the Lake Superior District," *Proceedings of the Lake Superior Mining Institute*, Vol. XXVIII (1930), p. 85.

[68] Several test pits as deep as 117 feet were sunk by pick and without a single drill hole or blast of powder. See Horace Winchell, "The Mesaba Iron Range," *The Engineering and Mining Journal*, Vol. LV, No. 8 (Feb. 25, 1893), p. 178.

[69] The following description of diamond drilling was given in *The Iron Ores of Lake Superior*, pp. 37-8:

"In diamond drilling, a string of hollow rods made in standard ten-foot lengths, is rotated by the drill engine through a shaft and gearing. At the bottom of [*Con.*]

introduced in 1869, diamond drilling was extensively used during the 1880's on the Marquette and Menominee ranges in Michigan and in the Lake Champlain District of New York. It was later used in all other areas where it was necessary to drill deep holes in rock and hard-ore bodies.[70] The diamond drill, capable of drilling angle holes as well as vertical holes, has proved to be a very satisfactory machine for exploring at great depths and has permitted the discovery of iron-ore deposits located underneath swamps and lakes.[71]

Diamond drilling, however, was ill-adapted to some of the conditions encountered on the Mesabi and later on the Cuyuna range where much of the material to be penetrated was soft. The churn drill, which chops and pounds its way through the ground by percussive rather than by rotative action, was found to be more suitable. The first prospect churn drills, introduced on the Mesabi range in the early 1890's, were adaptations of the hollow tool drill and jetting bit such as were commonly used at the time in drilling water wells.[72] A continuous flow of water, forced into and through the hollow drill steels, escaped through perforations near the cutting bit and flushed out the drill cuttings. These cuttings, delivered into settling tanks, were carefully collected and

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[69][*Con.*] the string of rods is screwed a core barrel, a core lifter and the bit. The bit consists of an annular ring of soft steel in which are set the carbons or 'black diamonds' which do the actual cutting. . . . . The tools and bit are fed forward by either screw or hydraulic feed, and as the bit, which is 1½ inches outside diameter, is fed forward, it cuts an annular hole about 1 $\frac{9}{16}$ inches in diameter leaving a $\frac{15}{16}$-inch core. Water is forced down through the rods, washing away the cuttings beneath the bit and carrying them up to surface in the space outside of the rods. The cuttings are collected by passing them through a 'sludge box' provided with baffles behind which they settle, the water running back to the sump.

"The core and cuttings combined from a five-foot run constitute the usual sample. At the end of a five-foot run, water continues to be pumped into the hole till it comes up clear of cuttings, the rods are pulled and the core removed from the core barrel. The cores are placed in a core box in proper order and are labelled. The cuttings and core are analyzed separately and the results combined in the proper proportion to give the average analysis for each five feet of hole. The cores are cut in half lengthwise in a 'core splitter' one half being used for the analysis and the other half being filed away as a permanent record."

[70]Cf. Elliott, Jopling, and Others, *op. cit.*, p. 125; also Brooks, *op. cit.*, pp. 1, 200, 204, 259; *Annual Report of the Commissioner of Mineral Statistics for Michigan for 1881* (Lansing, Mich.: W. S. George & Co., 1882), pp. 163-251; and also John M. Longyear, "Reminiscences of the Development of the Lake Superior Iron Districts," *Proceedings of the Lake Superior Mining Institute*, Vol. XXI (1916-17), p. 104.

[71]Jopling, *loc. cit.*

[72]The first churn drills were operated with either horse or steam power; later drills were operated with gasoline or electricity. The following description of an early churn drill is taken from E. J. Longyear, "Explorations on the Mesabi Range," *Transactions, A.I.M.E.*, Vol. XXVII (1897), pp. 537-8:

"A churning motion is given by passing a rope from the top of the drill-rods up through a sheave-wheel and down again, running two or three times around the drum of the engine, leaving the end loose. The drum continually rotates, and a man at the loose end alternately tightens and slackens the rope, thus raising and dropping the drill-bit at will. The bit itself usually has a single cutting-edge, rather thin toward the lower end, and a thread cut on the upper end, in order to attach it to the drill-rods . . . . . In surface-drilling a 3-inch casing of common gas-pipe and a 1¼-inch drill-rod are used. In ore, a 2-inch casing is put in after the 3-inch has been stopped, and a 1-inch drill-rod is used."

For a good description of prospect-drilling techniques on the Mesabi range around 1910, see van Barneveld, *op. cit.*, pp. 24-34.

analyzed. When the drill encountered a granite boulder, as frequently happened when penetrating glacial drift, it was customary to shatter the boulder with charges of dynamite after safeguarding the casing by pulling it away from the danger zone. Later, prospect churn drills were designed so that they could drill slanting holes that permitted the penetration of strata at right angles to their dip.

Although the first prospect churn drills used on the Mesabi range made satisfactory progress in soft overburden and soft ore, they were ineffective for penetrating rock, layers of hard ore, or taconite. There was later designed a combination churn- and diamond-drill outfit by which the former could be used for soft materials and the latter for rock and hard ore.

On the West Mesabi range, where the deposits are low-grade and where it is extremely important that the samples should represent the true tenor of ore, "structure drilling", a modification of the usual method of churn drilling, was introduced in 1914 and has since been generally adopted in that district. Instead of using a jetting bit in the form of a chisel, with the water being introduced through the drill rods and escaping between the drill rods and casing, the cutting and chopping are done by serrated teeth cut in a hollow round bit of approximately the same inside diameter as the drill rods. The water is introduced to the bottom of the hole between the casing and the outside of the drill rods and carries the chips and cuttings up through the drill rods. As the inside diameter of this cutting bit is appreciably greater than the space between the casing and drill rods, larger fragments are recovered and yield a more satisfactory sample for analyzing not only the chemical composition of but also the physical structure of ore bodies.[73]

The evolution of the present-day machines has brought about both an increase in the average footage drilled per shift and a decrease in the labor required to operate the outfits. In 1894 the rate of progress for prospect churn drilling on the Mesabi range was about 6 feet per shift.[74] By 1912 the average footage drilled per shift with the combination churn and diamond drill had increased to about 9 feet;[75] and in

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[73] H. C. Bolthouse, "Structure Drilling as Applied in Western Mesaba Mining Practice - The Exploration of Ore Bodies," *Proceedings of the Lake Superior Mining Institute*, Vol. XXIX (1936), pp. 220-3.

[74] Channing, *op. cit.*, p. 402.

[75] This is a rough average allowing for all time lost in break-downs, moving, and other delays. The average footage drilled per well per shift varies considerably, depending upon the nature of the material penetrated and trouble encountered with boulders, lost tools, etc.; the experience of the management and operators; the number of drills in operation; the availability of water and other supplies; the distance between holes and the condition of available roads; and the average depth of holes. Thus, although the average drilling speed per shift for the combination churn and diamond drill was about 9 feet, the churn drill could drill 10 to 100 [*Con.*]

1915 the average advance per shift on the Cuyuna range, drilling angle holes, was said to have been 15 feet or more.[76] Although prospect-drilling conditions vary considerably and the above three examples of the average footage drilled between 1894 and 1915 may not be a precise measure of the increase, it is apparent that there had been a substantial advance in drilling speed during that 20-year period. Furthermore, with the greater mobility of present-day machines, the general improvement of transportation facilities in the iron-mining districts, the substitution of electric and gasoline power for steam,[77] and with better knowledge of strata penetrated, drilling performance probably continued to increase substantially after 1912-15. While average footage drilled per shift has increased, the number of men required to operate a prospect-drilling outfit has declined from a little more than three men per outfit for machines used prior to 1912[78] to about two men for present-day machines.[79]

The volume of prospect drilling on the Mesabi range reached its height during about the first 15 years of the present century. In 1912 as many as 400 drilling outfits, both churn drills and diamond drills, were in more or less continuous operation in the Lake Superior District and

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[75] [*Con.*] feet per shift in glacial drift, 10 to 50 feet in soft shale, and 10 to 15 feet in ore. The diamond drill could advance 8 to 20 feet per shift in hard shale, 5 to 15 feet in quartzite, 6 to 10 feet in hard taconite, and 5 to 15 feet in decomposed taconite. See van Barneveld, *op. cit.*, p. 33.

[76] P. W. Donovan, "Some Aspects of Exploration and Drilling on the Cuyuna Range," *Proceedings of the Lake Superior Mining Institute*, Vol. XX (1915), p. 138.

[77] The introduction of gasoline-driven, combination churn- and diamond-drill outfits in northern Michigan in 1918 greatly reduced the time required in moving drills, as well as labor and fuel cost. The average time necessary to move a steam-driven outfit from one hole to another, from the time the casing was pulled until drilling started again, was 2½ days. The gas-driven outfits could be moved in 5 hours. See J. M. Longyear, Jr., "A Gasoline-Driven Diamond-Drill Outfit," *Engineering and Mining Journal*, Vol. 106, No. 8 (Aug. 24, 1918), pp. 343-4.

[78] The operation of one group of 30 combination churn- and diamond-drill outfits on the Mesabi range shortly before 1912 required 30 drill runners, 60 helpers, 5 pumpmen, 1 blacksmith, 3 diamond setters, 2 cooks, 4 stewards and waiters, 1 superintendent, 1 clerk, 2 foremen, and 3 samplers. Counting all these employees, the average was 3.7 men per outfit; excluding the cooks and others, there were 3.3 men per outfit. See van Barneveld, *op. cit.*, pp. 24-5.

In 1903 it was estimated that 1,000 men were employed on the Mesabi range to keep 250 prospect-drilling outfits in operation. See Dwight E. Woodbridge, "The Mesabi Iron Ore Range - V," *The Engineering and Mining Journal*, Vol. LXXIX (Feb. 16, 1905), p. 319. In 1911 it was stated that 40 drilling outfits were being prepared to prospect a part of the Mesabi range, giving employment to 150 men. See George E. Edwards, "Lake Superior Iron Mining," *Mining and Engineering World*, Vol. XXXV, No. 18 (Oct. 28, 1911), p. 856. In 1912 it was estimated that 1,400 to 1,500 men were employed on 400 drilling outfits in the Lake Superior country, or about 3.6 men per drill. See R. C. Allen and Others, "Mineral Resources of Michigan, 1910," *Michigan Geological and Biological Survey* (Lansing, Mich.: Wynkoop Hallenbeck Crawford Co., Pub. 8, Geol. Ser. 6, 1912), p. 125.

Woodbridge, Edwards, and Allen may have included geologists, engineers, surveyors, superintendents, foremen, cooks, and the like - and the number actually operating the drills may have been smaller.

[79] Some of the machines used today in prospect drilling are standard electrically operated blasthole drills, with some auxiliary attachments. Various mining companies used these in later years when they began to do their own exploration work instead of having it done by contractors. See Bolthouse, *op. cit.*, p. 222.

furnished employment to from 1,400 to 1,500 men.[80] Up to 1912 about 30,000 prospect drill holes had been put down on the Mesabi range - first discovered in 1890 - and 2,500 on the Cuyuna range, although ore on the latter was not discovered until 1904.[81] Between 1901 and 1909 the United States Steel Corporation spent one million dollars yearly in exploration work in Minnesota alone and put down drill holes with an aggregate length of 229 miles.[82] Since about 1915, however, there has been a reduction in the amount of prospect drilling, principally because no important iron-mining district has been located since the Cuyuna range discovery and because the general limits of the ore occurrences on the known ranges were fairly well established and most of the ore bodies have already been prospected.

Thus the volume of employment in prospect drilling in the iron-mining industry has declined, not only because of a reduction in the amount of labor required for an equal volume of prospect drilling but also because of a decrease in the total amount of prospecting work, despite more thorough prospecting.

Progress in Blasthole Drilling.- As previously observed, blasthole drilling at open-pit iron mines is much easier than at underground operations and requires a much smaller proportion of the total labor force.[83] Although troublesome granite boulders are frequently encountered in the glacial-drift overburden and occasionally it is necessary to penetrate layers of hard slate, taconite, and other rocks, most of the materials drilled at present-day operations are soft - generally softer than in underground iron mines,[84] or at open-cut copper mines, or in the majority of stone quarries. The most important exception is the material encountered in drilling at the siliceous iron-ore pits in Michigan, but these produced only 1.5 percent of the total output from open-pit operations in 1937. It has been found that shovel-loading efficiency is increased when overburden and ore banks are first shaken up at least with relatively light charges of explosive. In 1928 it was estimated that 80 percent of the overburden on the Mesabi range was being drilled

[80] Allen and Others, *loc. cit.*

[81] Van Barneveld, *op. cit.*, p. 207.

[82] Soper, *loc. cit.*

[83] See p. 53. At a typical stripping operation on the Mesabi range in 1911, the proportion of the total employees that were engaged in drilling and blasting varied from 11.2 percent under the poorest conditions in the coldest winter weather to 5.2 percent under good conditions during the summer. See van Barneveld, *op. cit.*, p. 168.

[84] In underground iron mines, however, about one-third of the product is hard enough to be mined in open stopes not requiring artificial support (see table A-22), and much more than this proportion of other materials drilled is hard rock.

and blasted;[85] probably an equal or smaller proportion of the ore also requires blasting.

All of the blasthole drilling at open-pit operations prior to the early 1880's - and most of it until after the World War - was done by hand with much physical human labor. Rock boring as practiced on the Marquette range in 1870 was described by Major T. B. Brooks in the following words:

> The steel used for drills is $1\frac{1}{4}$ inch octagon, with a bit 2 inches, making a hole nearly $2\frac{1}{4}$ inches in diameter. Drills vary in length up to 24 feet. . . . . The drill is turned by one man sitting and struck by two standing, with eight-pound hammers, at the rate of about thirty-six blows per minute each. In this way from nine to eleven feet of hole are sunk per day, the men working usually on contract. . . . . Very deep holes, say from fifteen to twenty-two feet, are sometimes sunk with still larger bits. . . . . In these cases two men are required to turn the drill and three to strike.[86]

Although power drills were tried in the 1870's,[87] the first instance of their continued and successful use in open-pit iron mining was at the Cornwall mine in Pennsylvania, where six compressed-air piston-type drills[88] were introduced in 1882. Each drill, operated by two men, was capable of drilling from 150 to 160 feet per 10-hour shift, boring 3-inch holes to a depth of 12 feet. Each of these drills was considered capable of doing the work of about 18 men using hand tools.[89]

The effect resulting from the introduction of piston-type drills for work in hard materials on output per man in drilling is also indicated by the example of the Portland Pit iron mine in Michigan in 1911. Prior to the introduction of power drills, 30 men were required for hand drilling enough material to keep one shovel in operation. These were replaced by six men and three heavy, compressed-air drills mounted on tripods.[90]

Machine drilling of blastholes on the Mesabi and Cuyuna ranges did not begin to displace hand labor until about 1910 and was not generally adopted until after the World War. A few piston drills were used in

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[85] Cash and von Bernewitz, *op. cit.*, p. 201.

[86] Brooks, *op. cit.*, p. 264.

[87] *Ibid.*, p. 266; see also Jopling, *loc cit.*

[88] This type of drill consists essentially of a cylinder into which is admitted air or steam to actuate a piston to which the drill steel is rigidly clamped. The piston delivers a succession of heavy blows, automatically rotating the drill at the same time.

[89] Lesley and d'Invilliers, *op. cit.*, p. 558.

[90] P. B. McDonald, "Stripping on Portland Pit Iron Mine, Michigan," *Mining and Engineering World*, Vol. XXXV, No. 4 (July 22, 1911), p. 147.

1911 where the ore was unusually hard[91] or where the operation was unusually well-equipped;[92] but until drill machines were greatly improved, hand methods sufficed, for the relatively soft materials encountered and the low benches did not require deep drilling.

The most common hand method of drilling ore on the Mesabi range was to put down vertical holes from the top of benches with a "jumper" drill. This was a long, chisel-pointed iron or steel bar, about 1 inch in diameter, that was grasped in the hands of from two to four miners and alternately lifted and plunged against the bottom of the hole; to facilitate the handling of the jump drill in deep holes up to 22 feet, a heavy cross-handle or yoke was sometimes attached to the drill rod at right angles to it. In 1918 a gang of jump-drillers working in soft ore averaged 50 feet of hole per man-day.[93] Since the diameter of jump-drilled holes was small, it was necessary to enlarge them near the bottom so that more explosives could be charged and fired, thereby breaking more ground with less drilling. This enlarging - called "springing" or "chambering" - was accomplished by exploding one or a succession of small charges of dynamite at the bottom of the hole prior to loading it with a larger charge for the final blast.

This method of drilling was seldom feasible in overburden,[94] especially if the height of the bank exceeded 15 feet or if the top was of hard materials; instead, almost horizontal holes, known as "gopher holes", were even more laboriously dug into the "toe" or base of the bank. These gopher holes - up to 25 feet in depth, 10 to 15 inches in diameter,[95] and sloping downward at angles of 5 to 20 degrees from the horizontal - were dug with long-handled shovels in soft materials and with long hand augers, making smaller holes, in somewhat harder materials. The latter were then enlarged with small charges of dynamite. The ends of the gopher holes were similarly chambered, and the loose material was shoveled out to make room for the big charges of explosives.

The hand methods described above were inadequate where deep drilling was required; the use of piston-type power drills permitted somewhat

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[91]The Biwabik mine was equipped with six compressed-air Ingersoll drills that drilled holes up to 24 feet in depth. See van Barneveld, *op. cit.*, p. 165.

[92]The equipment of a "well-managed" stripping operation listed a Chicago and a Murphy pneumatic air drill. *Ibid.*, p. 162.

[93]L. D. Davenport, "Steam-Shovel Mining on Mesabi Range - III," *Engineering and Mining Journal*, Vol. 105, No. 13 (Mar. 30, 1918), p. 581.

[94]Shallow top holes, 3 to 6 feet in depth, were often jump-drilled in frozen overburden on the Mesabi range with the use of drill rods heated to a dull red, and in badly frozen ground steam points were sometimes used. The cold winter weather often froze the ground to a depth of 8 feet. See L. D. Davenport, "Steam-Shovel Mining on the Mesabi Range," *Engineering and Mining Journal*, Vol. 105, No. 9 (Mar. 2, 1918), pp. 405-6.

[95]The earliest gopher holes were made large enough to permit a man to enter them, but this method was soon abandoned because of the danger involved.

deeper holes. During 1913-14 at the Virginia mine on the Mesabi range, electric air drills mounted on tripods and manned by a runner and two helpers were used to drill holes over 24 feet deep, including a few horizontal holes. About half of the material was hard, and it was estimated that the cost of hand drilling the same footage with the same number of feet through each kind of material would have been more than twice as much.[96] Piston-type drills used on the Mesabi range in 1918, evidently in softer materials, were said to average 90 feet of hole per drill per day, or an average of 45 feet per man-day (as each machine was operated by two men), compared to an average of 50 feet per man-day in jump-drilling. Although the limiting depth of hand jump-drilled holes was about 22 feet, the maximum depth of holes drilled by machine was 28 to 30 feet, and hard materials could be penetrated more easily.[97]

The largest labor-saving development in primary[98] blasthole drilling at open-pit iron mines, however, was the increased use of the well-type churn drill dating from the World War period. Unlike that of the earlier prospect churn drill, the cutting tool of the present-day churn drill is made of solid steel and is not hollow like the prospect drill. The drill cuttings are not continuously flushed out with water; instead, just enough water is let into the hole to make a "mud soup" by mixture with the cuttings, and after each few feet of drilling the drill tools are raised and the mixture is pumped out. Mobility of the drilling machine was a more important consideration in prospect drilling, where it was necessary to move long distances over rough country, than in the use of the churn drill for blasthole drilling. Here the moves were short, and heavier machines could be used that could strike more rapid and more powerful blows. However, with the adoption of caterpillar traction soon after the war, mobility was also secured.

The depth of churn-drill holes was not limited as was the case with holes drilled by hand methods or with piston-type drills. With the advent of large power shovels this was an important advantage, when deeper holes were necessary for breaking ground in higher benches.

The diameter of churn-drill holes was also large, 6 to 9 inches, whereas holes drilled by hand or with piston-type drills did not exceed about 3 inches in diameter and required considerable springing, which some-

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[96] "Record of Temple-Ingersoll Drills on the Mesabi Range," *The Engineering and Mining Journal*, Vol. 98, No. 24 (Dec. 12, 1914), pp. 1042-3.

[97] Davenport, "Steam-Shovel Mining on Mesabi Range - III," p. 581.

[98] Blast drilling that is done to break up the original mass is called "primary" drilling. The subsequent drilling necessary to break up rock fragments, hard lumps of ore, or boulders that are too large for the loading machine to handle is called "secondary" drilling.

times resulted in lost holes. Springing is more satisfactorily accomplished in the larger holes and is often not necessary at all. The large-diameter holes with their large powder-holding capacity may be spaced wider apart and fewer holes need to be drilled.

Although there were isolated instances of the use of churn drills for blasthole drilling in open-pit iron mines as far back as 1907 in New York,[99] and in 1911 in the Cornwall mine in Pennsylvania,[100] they were not generally adopted on the Mesabi range until within about the last 15 years. One observer of Mesabi range mining practice commented in 1914 that "no attempt has been made to employ churn drills for blasting purposes and with the relatively low benches carried, they would not seem to be applicable."[101]

The earliest churn drills, partly wooden, wheel-mounted, using manila rope, and driven by steam, were clumsy outfits, and their rate of penetration was slower than that of the piston drill.[102] By 1923 electric churn drills were at work on the Eastern Mesabi range; they put down holes 20 to 40 feet in depth and required but one operator per drill with a helper servicing three to five machines.[103]

At the Volunteer mine on the Marquette range in Michigan in 1927 and later years, a battery of churn drills riddled banks of hard ore with 6-inch holes ranging in depth from 60 to 90 feet in preparation for large field blasts.[104] The practice of breaking in one blast enough ground for a whole season of uninterrupted shovel loading, as developed since 1927 at the siliceous pits on the Marquette range, proved highly advantageous. Drilling was concentrated in one period and could be performed with the greatest efficiency, for the frequent placing and

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[99] Edwin Higgins, "Stripping Clinton Iron Ore in New York State," *The Engineering and Mining Journal*, Vol. LXXXVI, No. 24 (Dec. 12, 1908), p. 1151.

[100] Two of these drills were installed to put down deeper holes than could be drilled with piston-type air drills. Although the churn drills were slower, their holes were larger and deeper and probably permitted breaking as much material in a given time as the holes drilled by the piston-type drills. See E. B. Wilson, "The Cornwall, Pa., Magnetite Deposits," *Proceedings of the Lake Superior Mining Institute*, Vol. XVI (1911), p. 233.

[101] L. O. Kellogg, "Notes on Mesabi Range Mining Practice - I," *The Engineering and Mining Journal*, Vol. 97, No. 14 (Apr. 4, 1914), p. 698.

[102] Wilson, *loc. cit.*

[103] The material drilled was the hard taconite typical of this part of the range, and the rate of drilling with drill bits 6 to 7 inches in diameter was only 12 to 14 feet per 10-hour shift. See W. G. Swart, "Mesabi Iron Company's Reduction Plant," *Proceedings of the Lake Superior Mining Institute*, Vol. XXIII (1923), p. 113.

[104] The material penetrated was very hard, and the average footage drilled per machine per 9-hour shift in 1929 with electrically driven drills was 30 feet in red cherty hematite and 12 feet in hard, gray, sideritic carbonate. See L. S. Chabot, Jr., "Field Blasting at the Volunteer Mine," *Proceedings of the Lake Superior Mining Institute*, Vol. XXVII (1929), p. 262; also Max H. Barber, *Progress in the Improvement of Methods and Equipment at Open-Pit Iron Mines on the Lake Superior Iron Ranges* (American Institute of Mining and Metallurgical Engineers, Tech. Pub. No. 487, 1932), p. 1.

replacing of drilling machinery, track, and power shovels before and after each small blast were avoided; when the holes were properly spaced and charged with explosives, the simultaneous blasting resulted in better fragmentation, and the blasting hazard was reduced.[105]

By 1929 hand drilling was rare; and although the smaller piston, air, and steam drills were still used at some pits with low benches, the majority of the operations were using churn drills for all primary drilling, with boring rates for 6-inch holes of 15 to 80 feet per 10-hour day, depending on the hardness of material penetrated.[106]

Improvements in churn-drill design after 1929 have greatly increased their efficiency. It was said in 1932 that in the space of only 2 years the footage drilled per 10-hour shift had increased at least 50 percent and in some instances 100 percent.[107] In 1938 a modern churn drill, of the type shown in figure 21, was reported to have averaged over 200 feet per 8-hour shift at one large open pit on the Mesabi range.[108] Rigidly and durably constructed, with all-steel welded frames and derricks having a low center of gravity, and equipped with rubber shock absorbers, stabilizing jacks, and full-length caterpillar tractors, the machines operate more smoothly and uninterruptedly. The trend today is toward churn drills capable of drilling larger holes, up to 9 inches in diameter, at the same or higher drilling speeds. The large-diameter holes hold more explosives without chambering; consequently, the holes may be spaced farther apart and labor is saved because fewer holes need to be drilled.

Progress in Secondary Drilling.- Primary drilling and blasting often leave lumps of rock or hard ore which are too large for the power shovels to handle. The glacial-drift overburden contains many granite boulders ranging in size from 2 to 12 feet in diameter; in cold weather, moreover, there are large chunks of frozen material. Large pieces of taconite or other rocks are also found in the ore-bearing formations. These must all be broken before they can be loaded and hauled away.

Until about 25 years ago almost all of this work was done by hand. Sometimes large pieces were broken by men wielding heavy sledge hammers. In some of the early pits on the Marquette range around 1870, hammers weighing as much as 23 pounds were used to break large pieces, both to facilitate handling and to sort out country rock from ore.[109] Granite

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[105] Chabot, *op. cit.*, p. 270.
[106] Cash and von Bernewitz, *op. cit.*, p. 202.
[107] Barber, *op. cit.*, p. 5.
[108] *Skillings' Mining Review*, Vol. 27, No. 28 (Nov. 5, 1938), p. 5.
Footnote 109 appears on page 86.

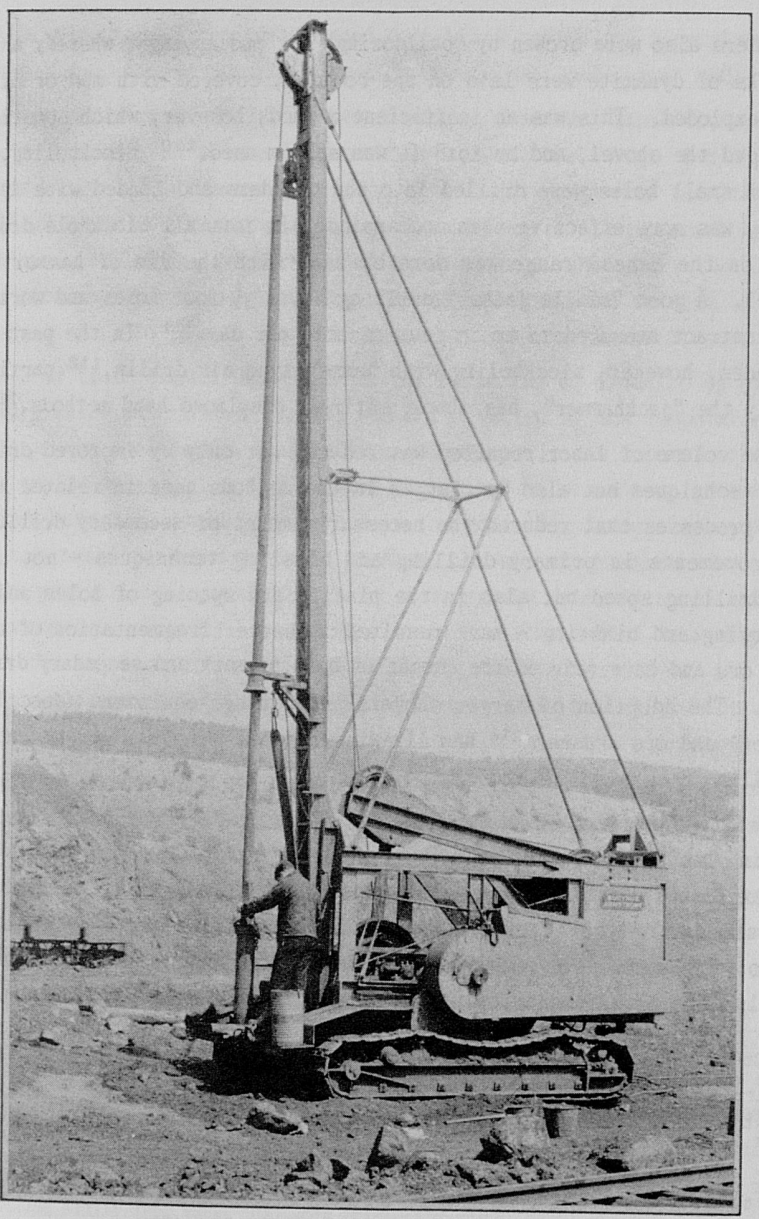


FIGURE 21.– A MODERN BLASTHOLE DRILLING MACHINE

The blasthole churn drill has rapidly come into prominence in open-pit iron mining since the World War. The trend is now toward heavier machines of the type shown, that can drill holes up to 9 inches in diameter and thereby reduce the number of holes needed. This drill penetrates rapidly by striking sharp, heavy blows with drill tools weighing more than a ton and traveling 40 inches or more per stroke. These machines are propelled by electric, gasoline, or Diesel power; are durably constructed with an all-steel welded frame and derrick and with a low center of gravity; and are equipped with 3-point suspension mounting, rubber shock absorbers, stabilizing jacks, and full-length caterpillar treads. They travel quickly between holes and require less labor for operation and maintenance.

boulders also were broken by "bulldozing" or "mudcapping", whereby a few sticks of dynamite were laid on the boulder, covered with mud or dirt, and exploded. This was an inefficient method, however, which sometimes damaged the shovel, and by 1918 it was seldom used.[110] Blockholing, by which small holes were drilled into the boulders and loaded with dynamite, was more effective than mudcapping. In 1911 all blockhole drilling on the Mesabi range was done by hand with the use of hammer and steel. A good "single jacker" drilling 2- to $3\frac{1}{2}$-foot holes and working on contract averaged 12 to 15 feet of hole per day.[111] In the past two decades, however, blockholing with hammer-type air drills,[112] particularly the "jackhammer", has almost entirely displaced hand methods.[113]

The volume of labor required was reduced not only by improved drilling techniques but also by changes in the methods used in related mining processes that reduced the necessary amount of secondary drilling. Improvements in primary drilling and blasting techniques - not only in drilling speed but also in the placing and spacing of holes and in charging and blasting - have resulted in better fragmentation of rock and ore and have reduced the amount of both primary and secondary drilling. The adoption of larger shovels and haulage equipment (described later) and ore crushers[114] has likewise reduced the amount of secondary drilling necessary.

Related Progress in Blasting.- The black powder originally used in mining has been replaced by nitroglycerin, dynamite, and a wide variety of explosive agents which are indispensable to modern mining technology. Liquid nitroglycerin, introduced on the Marquette range as early as 1870, was enormously more powerful than black powder and was particularly effective in shattering hard rocks. It was highly dangerous to

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[109] Commenting on the impracticability of using steam hammers such as were used in some copper mines at the time to break large pieces of ore, Major T. B. Brooks said of iron-ore pits:

"A steam miner who can walk up to the lump of ore and sledge it to pieces where it lies is what is wanted.

". . . . the difference in results, between the experienced miner who strikes the lump of ore the right blow in the right place, with his immense hand hammer, and the tyro, is very great." See Brooks, *op. cit.*, p. 267.

[110] Davenport, "Steam-Shovel Mining on the Mesabi Range," p. 406.

[111] See van Barneveld, *op. cit.*, p. 137.

[112] In this type of drill the piston moves freely in the cylinder and, acting like a hammer, delivers a rapid succession of blows to the end of the drill steel, which is loosely attached to the machine and automatically rotated by it. The drill steel is struck by the piston and is not attached to it as in the piston-type machine.

[113] Davenport, "Steam-Shovel Mining on the Mesabi Range," p. 406.

[114] For example, the Biwabik mine on the Mesabi range installed a crusher with a 21-inch receiving opening in 1901. Later a gyratory crusher was installed with a 48-inch opening, which could handle the largest and heaviest rocks that could be lifted by a 3-cubic-yard shovel. See van Barneveld, *op. cit.*, p. 165.

use, however, and dynamite replaced both black powder and nitroglycerin on the older, hard-rock ranges after it became available about 1881.[115]

In the soft materials of the newer ranges, however, quick-acting explosive agents such as the higher-strength dynamites[116] were not wholly satisfactory. The concussive effect of a light charge was too greatly localized, while a heavy charge was apt to scatter the material so as to hinder the loading performance of power shovels. Moreover, the dynamite froze at relatively high temperatures and could not be used in the frozen state. To thaw it was both dangerous and troublesome.

Both of these conditions fostered the replacing of dynamite by black powder, which was slow-acting and was not affected by low temperatures. Black powder had certain disadvantages, however; it was a comparatively weak explosive agent, and the loose grains had to be made up into cartridges before it could be inserted in the hole.[117] Since black powder was more sensitive than dynamite to heat, its use was hazardous because of the possibility of its ignition by stray sparks from the steam shovel or locomotive. Finally, it was so slow in its action that in some pits where the material contained many seams or cracks the force of the explosion was apt to be dissipated along them rather than to shake up the body of the material.

As the soft-ore excavations were developed, especially on the Mesabi range, the accepted practice was to spring drill holes with small charges of dynamite and then use black powder for the main blast.[118] Later, special explosives were developed that were more suitable to conditions encountered. A quicker initial explosive action was secured with "Judson powders", which were introduced sometime previous to 1900.[119] These consisted of mixtures of black powder and small percentages of nitroglycerin and were used in soft rock that contained many seams or cracks. Also, about the turn of the century, ammonia dynamites and later some nitrostarch powders were introduced. These explosives were either nonfreezing or froze only at low temperatures, and they were

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[115] Arthur P. van Gelder and Hugo Schlatter, *History of the Explosives Industry in the United States* (New York: Columbia University Press, 1927), p. 424.

[116] The lower-strength dynamites (less than about 30 percent nitroglycerin) did not come into general use until about the time of the World War. For a good description of the characteristics of various explosives, see Charles S. Hurter, "Blasting Explosives and Their Accessories," *Proceedings of the Lake Superior Mining Institute*, Vol. XXI (1916-17), pp. 141-94.

[117] Pellet powder, which is essentially black powder pressed into cartridge form, was not developed commercially until 1926-27; by that time other forms of explosives had supplanted black powder to a great extent.

[118] Channing, *op. cit.*, p. 396.

[119] Charles S. Hurter, "The Proper Detonation of High Explosives," *Proceedings of the Lake Superior Mining Institute*, Vol. XV (1910), p. 168.

slower-acting than straight dynamite. Some types came in a loose granular form so that they could be poured into a hole. The development of explosives of varying strengths that froze only at low temperatures resulted in an appreciable decrease in the use of black powder. By 1937, according to United States Bureau of Mines data, it made up less than 5 percent of the total amount of explosives used at open-pit mines.[120]

Drilling and blasting improvements in open-pit iron mining in the past half-century have thus directly increased output per man by reducing the labor required for breaking ground. Along with other technological advances they have made possible the expansion of the labor-saving open-pit method of mining, for they have facilitated the use of higher benches to take advantage of larger shovels and to permit haulage economies; and, by breaking ground better, they have speeded the loading of thicker overburdens and harder materials.

Improvement of Power-Shovel Loading

None of the technical developments at open-pit iron mines in the past half-century have had so large an influence on the expansion of open-pit mining and probably none have reduced unit labor requirements to so large an extent as the introduction and improvement of power-shovel loading. In fact, other functions have been adapted and largely subordinated to the effective operation of the power shovel. Even the first crude power shovels, each with a crew of about 10 men, accomplished 6 to 12 times as much work as could be performed by an equal number of men with hand-labor methods.[121] Power-shovel techniques have been steadily improved, however, until one of the most modern and efficient shovels, with one-fifth the former crew, can load about 10 times as much material as the shovels used at the beginning of the century. Whereas the early Mesabi power shovel manned with a crew of from 7 to 12 men[122] loaded

[120] Better results were obtained with black powder after the introduction of the Cordeau detonating fuze shortly after the World War. When churn-drill holes were column-loaded with black powder and detonated with the ordinary electric cap, the velocity of detonation was so low that there was an appreciable lag between the explosion of the powder next to the cap and that farthest away from it. This resulted in an appreciable loss in blasting efficiency. Cordeau, which consists of a thread of TNT encased in a lead sheath and which is in contact with a column of powder throughout its length, has so high a velocity of detonation that the whole column of powder is exploded simultaneously.

[121] It was stated in 1893 that a steam shovel could do the work of from 60 to 120 men, the biggest labor savings being achieved on large jobs and especially in harder and more tenacious materials. See E. A. Hermann, "Steam Shovels and Steam Shovel Work," *Engineering News*, Vol. XXX, No. 5 (Aug. 3, 1893), p. 91.

[122] The crew consisted of a shovel engineer, fireman, craneman, four to seven pitmen (mainly for moving the shovel), and sometimes included track cleaners; employees who were engaged in ore sorting or secondary drilling and blasting are not counted as part of the crew. See "Iron - Mesaba Range," *The Engineering and Mining Journal*, Vol. LVI, No. 9 (Aug. 26, 1893), p. 222; also Thomas, *op. cit.*, p. 153; and van Barneveld, *op. cit.*, pp. 146, 149.

1,000 to 2,000 tons of ore in 10 hours,[123] 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.[124] This advance in shovel-loading efficiency is not entirely the result of power-shovel improvements. It reflects advances in all mining techniques. Indeed, shovel performance is so closely related to the efficient operation of other mining functions, such as drilling and blasting, haulage, and dumping, that the increase in the amount loaded per shovel-shift may be taken as a good indicator of the general technological progress at open-pit mines.

Although a few power shovels were used before 1890,[125] their general adoption in open-pit work began with the opening of the Mesabi range in 1892;[126] by 1909 a total of 321 steam shovels were employed in iron mining in the United States.[127] All the power shovels used in iron mining prior to the World War were of the steam-driven railroad type.[128]

Disadvantages of the Early Steam Shovels.- The operation and maintenance of the early shovels required the service of many employees who were not needed with later improved models. Since the shovels were steam-driven, they had to be supplied with coal and suitable boiler water. This required coal handling, maintenance of water lines, occasional boiler cleaning, and precautions against freezing in wintertime. A fireman was needed to fire the boiler when the shovel was operating, and during periods of temporary idleness someone had to bank the fire to keep the shovel in readiness for work.

The swinging, hoisting, and thrusting motions of the shovel were controlled by two men instead of by one as on modern shovels. The shovel engineer, stationed near the engine, operated the swinging and hoisting mechanisms, while the craneman, stationed on a small platform attached to the crane or boom, controlled the thrust of the dipper and pulled

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[123] See Channing, *op. cit.*, p. 396; also Thomas, *op. cit.*, p. 153.

[124] W. L. Taylor, "The Mesabi Iron Range," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929), p. 791.

[125] Power shovels were used in Michigan as early as 1884 or 1887, in New York in 1888, and in Alabama in 1889. See *Skillings' Mining Review*, Vol. 23, No. 13 (July 28, 1934), p. 9; also a letter to the editor from J. Parke Channing, "Steam-Shovel Mining," *Mining and Scientific Press*, Vol. 102, No. 15 (Apr. 15, 1911), p. 532; also Higgins, *op. cit.*, p. 1151; also *Eleventh Census of the United States: 1890*, "Report on Mineral Industries" (U. S. Dept. Int., Census Office, 1892), p. 20.

[126] The first shovel on the Mesabi range was installed at the Biwabik mine in 1892 and was set to work stripping overburden. Another small shovel weighing 27 tons was introduced in the following year and successfully stripped several hundred thousand cubic yards of overburden. See van Barneveld, *op. cit.*, p. 40.

[127] *Thirteenth Census of the United States: 1910*, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), p. 259.

[128] In this type of shovel the boiler and the power units are mounted on a car frame, and only the boom, dipper stick, and dipper revolve through an arc of 180 to 240 degrees.

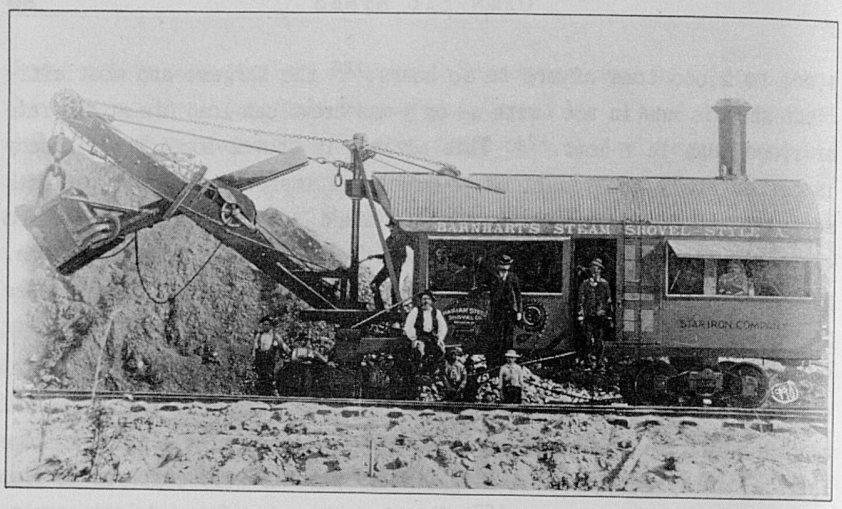


FIGURE 22.- ONE OF THE FIRST STEAM SHOVELS ON THE MESABI RANGE

This is believed to be one of the first two power shovels to be used on the Mesabi range and was set to work in 1893. It is an early model railroad-type steam shovel, equipped with an upright boiler and a single 2-cylinder engine that supplied the power for all three shovel motions - hoisting, swinging, and crowding. The swinging and hoisting motions were transmitted by means of friction clutches, for crowding power was taken from the hoisting action at the upper end of the boom through a chain drive and a friction clutch near the middle of the boom. Early shovel-loading operations were interrupted frequently because of mechanical failures and the need to adjust or replace friction clutches. Later improvements reduced these interruptions.

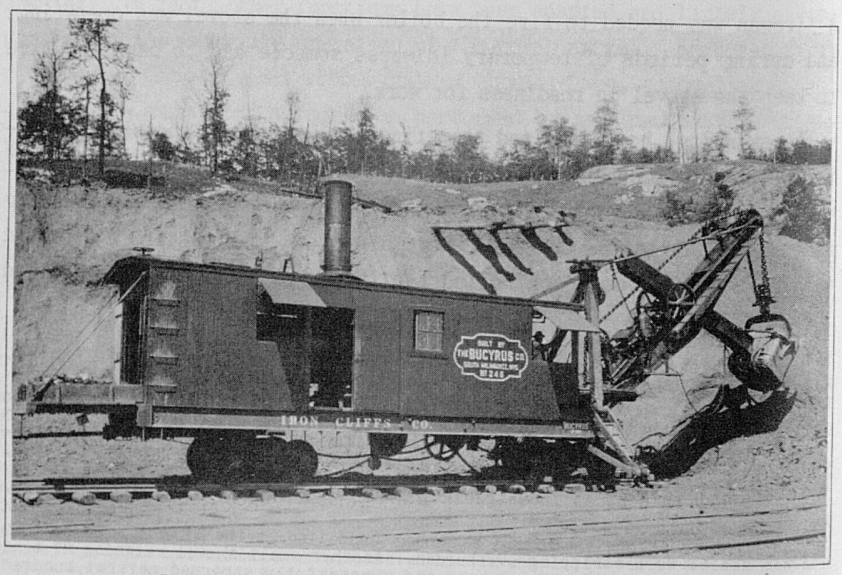


FIGURE 23.- AN EARLY RAILROAD-TYPE STEAM SHOVEL

This type of shovel required a relatively large crew to operate, move, and repair. With a crew of about 10 men it could load only about one-fifth the amount of ore that can now be loaded in the same length of time by a modern shovel with a crew of only 2 or 3 men. Despite their shortcomings when compared to modern loading equipment, the use of railroad-type steam shovels was a vast improvement over hand-loading methods.

the spring latch that opened the dipper door. To perform these functions properly and simultaneously required a high degree of skill and coordination.

Moving the shovel from place to place was a laborious and time-consuming task. Four to seven pitmen, or more than half of the whole crew, were needed even for the usual short moves. The shovels ran on rails, and track sections had to be laid for each forward move. Moreover, to prevent the long and narrow shovel from tipping when digging from one side, it was fitted with sidearms protruding from the shovel near the front end. These sidearms were equipped with jackscrews at their outer extremities, thus providing a means of keeping the shovel level and supporting it on uneven ground. For every move of the shovel, these jacks had to be taken up, the blocking carried to the new position, and the jacks readjusted. When loading from a 25- or 30-foot bank, the shovel would have to be moved 5 or 6 feet about once an hour. During the loading period the pitmen prepared the roadbed and carried rails and ties forward for the next move. Moving consumed from 5 to 25 percent of the total working time, depending upon the conditions of the particular operation. For long moves of about a quarter of a mile, the railroad-type shovel required the services of 30 to 40 men as compared to the 5 or 6 men needed for moving a modern shovel. Twice the number of railroad-type shovels as compared with full-revolving, caterpillar-mounted machines were needed to provide for a sufficient variety of ore to satisfy shipping requirements. A shovel working in a grade of ore that was no longer needed was simply stopped, and another shovel working in the correct grade was started up.

The relative instability and awkwardness of railroad-type steam shovels resulted in frequent break-downs that interrupted mining operations and added to the repair and maintenance labor requirements.[129] This was particularly true of the earlier shovels that were not built so sturdily as later models, as well as of those that were operated by many friction clutches requiring frequent adjustment or replacement.[130]

Despite the shortcomings of the railroad-type shovels, they were far superior to hand-loading methods and were an important factor in the rapid growth of open-pit mining. Moreover, by the time of the World War these shovels were greatly improved, and many are still performing useful

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[129] The following interesting comment was made in 1896: "This subject of breakage is one of the most serious that confronts the mine superintendent. When he first begins to use a steam shovel (I am now describing the general run of shovels) it breaks down at a most unfortunate time and causes no end of annoyance and expense." See A. W. Robinson, "The Steam Shovel in Mining," *Proceedings of the Lake Superior Mining Institute*, Vol. IV (1896), pp. 60-1.

[130] Hermann, *op. cit.*, Vol. XXIX, No. 18 (May 4, 1893), p. 409.

service. Improvements in shovel design came gradually, as a result of constant effort by shovel manufacturers and mining companies working in close cooperation. The upright boiler was replaced by the locomotive type; the single engine with friction-clutch power transmission gave way to independent steam engines for each of the three shovel actions. The shovels were built bigger and stronger without a corresponding increase in operating crews. The weight of the shovel was increased from 27 tons to about 100 tons and the dipper capacity from less than 1 cubic yard to 4 or 5 cubic yards. After about 1910 the hoisting mechanism of shovels was improved by replacing the usual chain and multiple sheaves or pulleys with wire rope and one large sheave wheel. This greatly increased shovel-loading efficiency, not only by substantially reducing friction in power transmission but also by permitting a shorter boom without a decrease in height of shovel lift.[131]

Increased Loading Efficiency of Full-revolving Shovels.- The introduction of full-revolving shovels[132] about 1915-20[133] was a long forward step in shovel design. This type of shovel could dig and deliver material equally well in all directions from one position.[134] Unlike railroad-type shovels, it did not need to be of the same width as the standard railroad track but was built on a wider and sturdier base. As a result, jack-arm supports were no longer necessary and the size of the shovel could be greatly increased. Although the craneman was indispensable on railroad-type steam shovels, he was no longer needed on revolving shovels. The engineer always faced the dipper and could control its action without the aid of the craneman.

The first full-revolving shovels used in open-pit iron mining were large, long-range excavators weighing about 350 tons. They were equipped with long booms and dipper sticks and with dippers of 6- to 8-cubic-yard capacity. Although in 1919 there were fewer than 10 of these large shovels in use in iron mining in the United States,[135] by 1924 a total of 24 were being used in the Lake Superior District. (See table 13.)

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[131] See van Barneveld, *op. cit.*, p. 140; see also Robert Marsh, *Steam Shovel Mining* (New York: McGraw-Hill Book Co., 1920), pp. 27-8.

[132] On these shovels the boom is rigidly attached to the upper frame that forms the base of the power units, and both revolve through a complete circle while the lower frame with the railroad or crawler trucks remains stationary.

[133] W. F. Schwedes, "Mechanical Shovels," *Proceedings of the Lake Superior Mining Institute*, Vol. XXVIII (1930), p. 107.

[134] The possibility of revolving the boom completely also permitted the use of the full-revolving shovel to aid in laying its track sections. This was accomplished by attaching the rear sections to the dipper and swinging them around to the front. In a similar manner granite boulders or other large fragments encountered in digging were sometimes moved to the rear of the shovel where their drilling and blasting did not interfere with loading operations.

[135] Earl E. Hunner, *Some Recent Developments in Open-Pit Mining on the Mesabi Range* (American Institute of Mining and Metallurgical Engineers, Tech. Pub. No. 333, 1930), pp. 4-5.

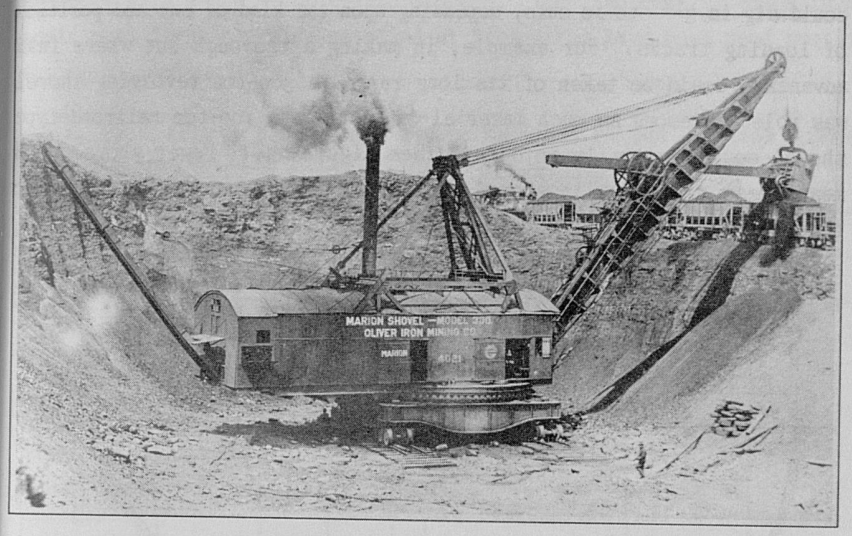


FIGURE 24.- ONE OF THE FIRST LONG-RANGE, FULL-REVOLVING SHOVELS USED AT IRON MINES

This shovel, working in the Hull-Rust open-pit mine at Hibbing, Minnesota, is one of the first long-range, full-revolving shovels used on the Mesabi range. It is capable of turning in all directions and is equipped with a 90-foot boom, a 50-foot dipper stick, and an 8-cubic-yard dipper. This shovel is excavating one large cut where as many as 10 cuts would have been required with the usual railroad-type shovel. As a result, less track-laying work and fewer forward moves are required, and interruptions to loading are less frequent.

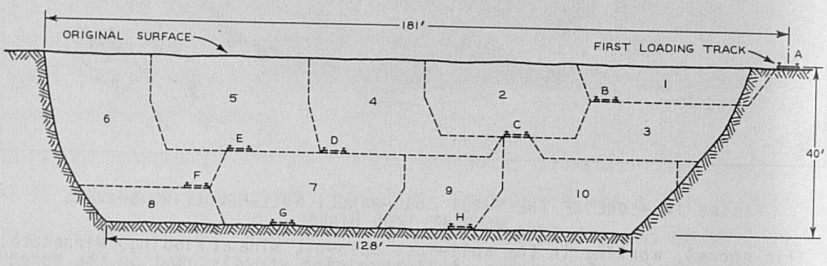
Track Laying Reduced by Using Large Shovels.- At large-scale operations where the use of big shovels was practicable, important track-laying and other labor economies were realized. The smaller, short-range, railroad-type shovels loaded from banks 20 to 25 feet high, and cars were spotted on loading tracks at the same elevation as the shovels; but the long-range, full-revolving shovels, which were able to dig from banks 30 to 36 feet high and which could load cars spotted on top of the banks above the shovels,[136] simplified the haulage problem. It was possible to avoid steeper grades or longer hauls at the same grades (with perhaps an additional haulage bench). As a result, trains of the same size and speed could be used despite increasing depth of pits, and the labor needed to prepare additional haulageways and to lay and maintain additional track was avoided.

The long booms and dipper sticks of the large shovels greatly increased their horizontal as well as their vertical digging range. Since the shovels were capable of digging over a wide radius, they could excavate as much material in 1 cut as the smaller, railroad-type shovels

[136] R. S. Walker, "The First Complete Electrification of an Open-Pit Iron-Ore Mine in Minnesota," *General Electric Review*, Vol. XXVII, No. 9 (Sept. 1924), pp. 583-4.

could dig in 3[137] to 10 cuts, depending upon the kind of cut and position of loading tracks. For example, in making a thorough cut where full advantage could be taken of its long range, a 360-ton revolving shovel was able to remove as much material in 1 cut as a 100-ton railroad-type shovel could remove in 10 cuts. (See figure 25.) Fewer shovel cuts meant less time lost in shovel moving and less track laying both for the shovel and the loading trains.[138]

Figure 25.- CROSS SECTION OF A THOROUGH CUT MADE BY A 360-TON FULL-REVOLVING SHOVEL AND CUTS REQUIRED TO REMOVE SAME AREA WITH A 107- TO 123-TON RAILROAD-TYPE SHOVEL



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The small divisions numbered 1 to 10 represent the successive cuts which would have been necessary for a 107- to 123-ton railroad-type shovel with a dipper capacity of 2½ to 4 cubic yards. On the other hand, this entire section could be removed in one cut, and from the same loading track, by a 360-ton full-revolving shovel with a dipper capacity of 6 to 8 cubic yards. The positions of the 8 loading tracks for 10 successive cuts by the smaller shovel are lettered from A to H.

Since large shovels were introduced before the adoption of caterpillar traction, they also required track laying, but the large shovel needed to traverse the length of the cut once, while the smaller shovel would have had to make 10 trips; and, although the width of the large shovel required two parallel sets of track, compared to one set for the narrower railroad-type shovel, the latter would have required track for 10 cuts instead of 1.

Moreover, since the range of the large shovel enabled it to load 10 times as much material per foot of advance and each advance was longer, its forward moves were much less frequent and loading was much more continuous than would have been possible with the smaller shovel.

Diagram adapted from L. D. Davenport, "Steam-Shovel Mining on the Mesabi Range," *Engineering and Mining Journal*, Vol. 105, No. 9 (Mar. 2, 1918), p. 404.

Because of the limited size of individual operations and other factors, very large shovels are not used at the majority of mines. The most popular models, in fact, are those with dipper capacities of 3 to 5 cubic yards. In 1924, for example, only 24 of the 447 excavators in use at all iron mines were in the 350-ton class with dipper capacities of 6 to 10 cubic yards. More than half were 90- to 100-ton shovels

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[137] Barber, *op. cit.*, p. 7.

[138] It should be noted that large shovels could be stationed farther away from the banks and thereby avoided difficulties resulting from slides. Moreover, since the larger dippers could handle bigger fragments, the amount of secondary drilling was also reduced.

equipped with 3- to 5-cubic-yard dippers. (See table 13.) Since 1924 additional large shovels installed at iron mines have been used mostly for overburden stripping.[139]

Table 13.- NUMBER OF SURFACE POWER SHOVELS IN USE AT IRON MINES IN THE LAKE SUPERIOR DISTRICT IN 1924, BY SIZE[a]

State and range	Size (tons)				
	Total	35-50	70	90-100	350
Minnesota					
Mesabi	347	37	87	202	21
Cuyuna	20	1	13	5	1
Vermilion	5	-	2[b]	3	-
Michigan					
Marquette	19	-	15	4	-
Gogebic	42	6	15	19	2
Menominee	14	-	9	5	-
Total, all ranges	447	44	141	238	24
Total, by kind of power used					
Steam	438	43	139	237	19
Electric	9	1	2[b]	1	5

[a]Data from R. S. Walker, "The First Complete Electrification of an Open-Pit Iron-Ore Mine in Minnesota," *General Electric Review*, Vol. XXVII, No. 9 (Sept. 1924), pp. 584-90. Shovels used by stripping contractors and for loading ore from stock piles at underground mines are probably included.
[b]60-ton shovels.

The fullest labor-saving advantages of large shovels were not realized, however, until after the change from steam to electric power and after the replacement of railroad trucks by caterpillar mountings. Until 1920 all large, full-revolving shovels used in iron mining were steam-driven,[140] and until about the middle twenties all were mounted on railroad trucks. The introduction of caterpillar traction in the post-war period has greatly facilitated the movement of shovels from one cut to another. The elimination of track laying for shovels reduced the disadvantage of small shovels in comparison to larger ones because of the necessity of making a larger number of cuts to remove the same amount of material. The new mobile, quick-swinging, electric shovels with 3- to 5-cubic-yard dippers are much more efficient than

[139]The largest power shovel at iron mines in the Lake Superior District is a 640-ton electric machine equipped with a 12-cubic-yard dipper. It is used by a stripping contractor. See *Proceedings of the Lake Superior Mining Institute*, Vol. XXVIII (1930), p. 25.
[140]Walker, *op. cit.*, p. 584.

the older railroad-type steam shovels of the same size. Although they do not have the digging range and dipper capacity of the larger shovels, they are much faster and can load almost as much material in the same time. The smaller, more flexible shovels also are better adapted for controlling the grade of ore, for digging in low banks that are often unavoidable, for clean-up work, and for the recent development of loading into trucks.

Adoption of Electric Shovels.- The introduction of electric shovels was one of the first of a rapid succession of technological improvements in the post-war period and had far-reaching effects on output per man at open-pit mines. Electric shovels are much more efficient than their steam-driven predecessors. They eliminated the labor formerly needed for firing, for supplying coal and water, for installing and maintaining water lines, and for boiler cleaning. The operation of the electric shovel is smoother and quieter since the more clumsy reciprocating action of steam engines is replaced by the rotary motion of electric motors. Since electric shovels are also cleaner and faster, working conditions are made more pleasant and loading efficiency is increased.

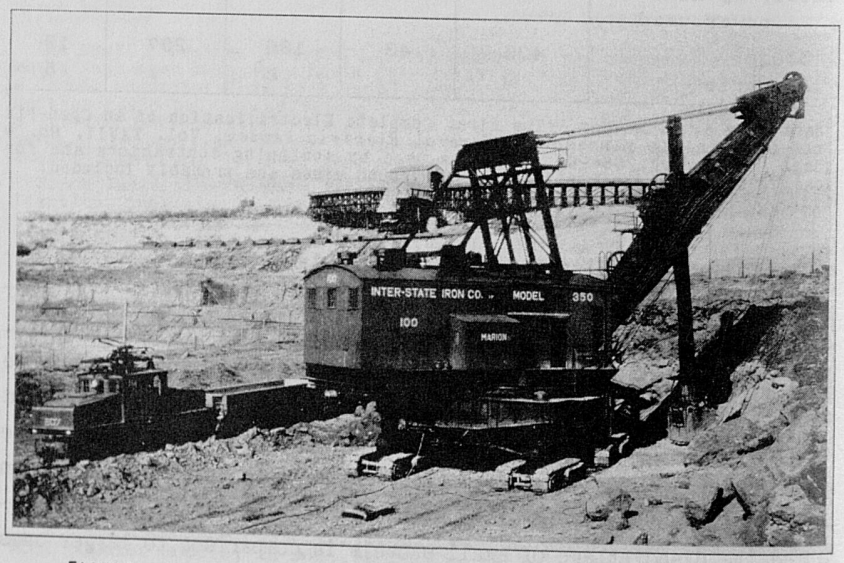


FIGURE 26.- A LARGE ELECTRIC SHOVEL LOADING AN ELECTRIC TRAIN

Electric shovels are easier to operate and to maintain than steam shovels of the same size, and they work more smoothly and more efficiently. This large shovel, with an 8-cubic-yard dipper and a long boom and dipper stick, has a large digging radius that enables it to load rapidly with little track shifting for the ore trains.

The train shown is hauled by an electric trolley locomotive. Electric locomotives are more powerful and can negotiate steeper grades and sharper curves. The post-war period was marked by a growth in the use of electric power for haulage as well as for loading.

The Ward-Leonard system of control was built into the first electric shovels used in iron mining and is now a standard feature of all electric shovels.[141] In this system an individual electric generator supplies current for each shovel motion, and the motions are easily controlled by varying the voltage of the generators. It affords an economic and efficient use of power, for it permits heavy motor loads at slow speeds or light loads at high speeds, whichever is most needed.[142] Moreover, by employing the motors to retard motion in such a manner that they not only serve as brakes but also generate power and return it to the line, this system serves to save power and eliminate mechanical brakes and clutches. Ward-Leonard control has also provided a simple and automatic means of preventing an excessive flow of current to the motors, thereby safeguarding the shovel against serious mechanical damage. This has meant a reduction in the frequency of shovel break-downs and a saving in the amount of time and labor needed for repairs.[143]

The first two electric shovels used in iron mining in 1920 were large 350-ton machines mounted on railroad trucks.[144] With further improvements in electric-shovel design, especially with the adoption of caterpillar traction, the use of electric shovels after 1924, both large and small, expanded rapidly. By 1937 about 41 percent of the shovels in use at open-pit iron mines were driven by electric motors, 43 percent by steam engines, and 16 percent by gasoline or Diesel engines.[145] Since iron-mining companies practically ceased purchasing new steam shovels after 1929 and as the older machines are being gradually worn out, the proportion of steam units in use will continue to decline in the future.[146]

Caterpillar Traction Made Biggest Cut in Shovel Crews.- One of the most important labor-saving changes in power-shovel design was the introduction of caterpillar traction beginning in 1922.[147] This improvement not only eliminated most of the crew formerly required by railroad-type

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[141] See Schwedes, *op. cit.*, p. 110.

[142] See R. W. McNeill, "The Electric Power Shovel," *Engineering and Mining Journal*, Vol. 122, No. 20 (Nov. 13, 1926), pp. 764-8.

[143] Records kept for 4 years indicated that the repair and maintenance cost of 350-ton electric shovels averaged $5,000 per year compared with $25,000 for steam shovels of the same size. See Walker, *op. cit.*, p. 588; also Hunner, *op. cit.*, p. 5.

[144] Walker, *op. cit.*, p. 584; also Hunner, *op. cit.*, pp. 4-5.

[145] According to reports of iron-mining companies to the U. S. Bureau of Mines. The total of 197 power shovels classified by kind of power used excluded shovels used by stripping contractors and a small number used at underground mines for loading ore from stock piles.

[146] It has been estimated that with proper care the life of a steam shovel is about 12 to 15 years. (See van Barneveld, *op. cit.*, p. 145.) A few have been in service much longer than this - up to 35 years.

[147] Bradlee Van Brunt, "Caterpillar Mounting vs. Railroad Type Shovels for Quarries," *Rock Products*, Vol. XXVI, No. 26 (Dec. 29, 1923), p. 92.

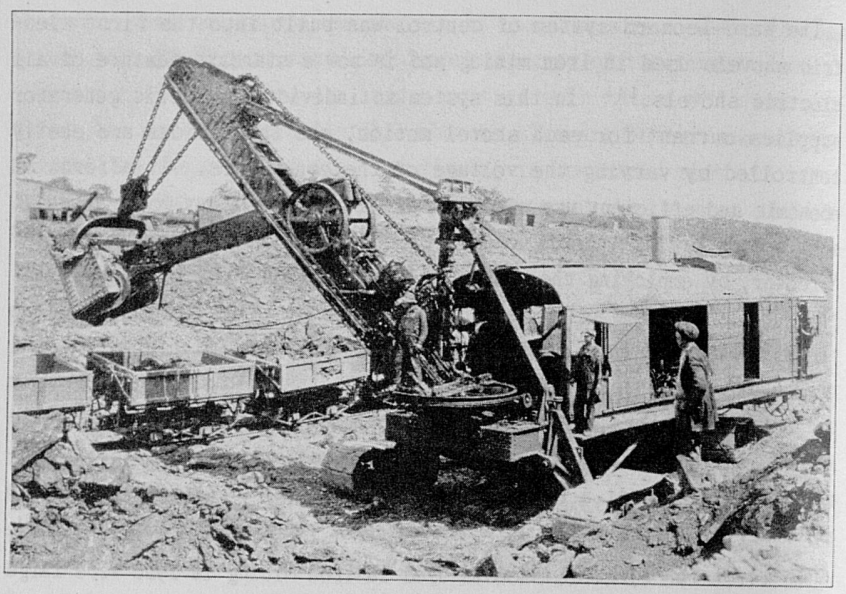


FIGURE 27.- CRAWLER-MOUNTED RAILROAD-TYPE SHOVEL

The adoption of caterpillar traction for power shovels in the post-war period was one of the most important labor-saving changes in power-shovel design. It eliminated most of the shovel crew formerly needed to move the shovel and greatly increased loading efficiency. On many railroad-type shovels, trucks were replaced with crawler mountings as in the shovel shown in this picture. Shovels specially designed for these mountings and equipped with a single pair of large caterpillars are still more flexible.

shovels but also greatly increased their effective working time and loading efficiency. As previously observed, the routine movement of shovels mounted on railroad trucks required the labor of from four to seven pitmen. The use of caterpillar mountings or crawlers, that had been developed as a result of war experience, reduced the number of pitmen to only one for shovels with dippers up to 5-cubic-yard capacity.[148] Since crawler-mounted shovels were capable of moving faster, a larger part of the time could be used for loading. By making quick moves between trains or even while swinging the boom back from the loading car, the operator could keep the shovel at the most effective distance from the bank and fill the dipper more easily.

The advantages of caterpillar-mounted shovels were so great that many mining companies replaced the railroad trucks under their old shovels with crawlers. (See figure 27.) In such cases the front jacks were each replaced with a single crawler and the rear truck by a double crawler. Although the movement of the railroad-type shovels was greatly improved thereby, their mobility was less than that of modern full-revolving shovels mounted on a single pair of large caterpillars.

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[148] Barber, *op. cit.*, p. 6.

Recent Trends in the Use of Power Shovels.- Loading operations at open-pit mines during the past decade have been characterized by a more widespread use of full-revolving, caterpillar-mounted, electric shovels or draglines[149] that had already been developed by the middle twenties.[150] In addition, there has been an increase in the use of small, self-contained, gasoline, Diesel, and Diesel-electric shovels. These small shovels have great flexibility and are particularly useful for work in small ore bodies or confined quarters, for shallow digging, and for loading into trucks.

Modern power shovels are built more compactly and more sturdily with less unnecessary dead weight than the machines they replace. A larger use of alloy-steel castings in frames and bases in place of plates and rivets has increased shovel rigidity and strength. The weight of dippers, dipper sticks, and booms has also been reduced, without a sacrifice in strength. This was accomplished by better designing and by using lighter-weight, higher-strength, alloy steels and welded instead of bolted or riveted sections. It has permitted a faster-swinging boom and a larger-capacity dipper without adding to the power requirements of the shovel. A reduction in the dead weight of dippers, for example, has resulted in a 10- to 25-percent increase in their pay-load capacity, a $4\frac{1}{2}$- to 5-cubic-yard dipper replacing one of 4 cubic yards.[151] Modern shovels are designed so that worn or broken parts can be easily removed and replaced, thereby diminishing the idle time of shovels as well as the necessary amount of repair and maintenance labor.

The loading efficiency and general mobility of power shovels have been increased so much in the post-war period that despite a continued

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[149]Dragline excavators have occasionally been used at iron mines, mostly for stripping, when their long reach and ability to dig from a level lower than the machine were a decided advantage. Equipped with a 155-foot boom, a dragline can make a cut 50 to 60 feet deep. Where waste may be deposited just beyond the rim of a small pit, a dragline can be employed without locomotives and dump cars. Sometimes it has been necessary to use a dragline because the soft nature of the bottom of a cut would not support a shovel. Modern shovels are usually built so that their booms may be readily replaced with longer ones for use with draglines. See Charles E. Lawrence, "Drag-line Stripping and Mining, Balkan Mine, Alpha, Mich., Menominee Range, Mastodon District," *Proceedings of the Lake Superior Mining Institute*, Vol. XX (1915), pp. 174-80; also Walker, *op. cit.*, p. 584; and Hunner, *op. cit.*, p. 5.

[150]The extent of the adoption of improved power shovels is reflected in a decline in the importance of certain occupations in shovel-operating crews. Thus, for example, even in such a short interval as 1924-31 the number of pitmen declined from 10.1 to 4.3 percent of the total employees at open-pit mines, shovel firemen from 3.8 to 1.9 percent, and shovel cranemen from 2.2 to 1.2 percent. Caterpillar traction reduced the number of pitmen required for track laying, and the wider use of full-revolving electric shovels eliminated the need for shovel firemen and shovel cranemen. (See table A-15.) The adoption of these improved types of shovels was by no means completed by 1931, and the trends indicated probably continued after 1931.

[151]See F. C. Ruhloff, "Increased Speed and Flexibility Characterize Improvements in Open Pit Machinery," *Mining Congress Journal*, Vol. 24, No. 7 (July 1938), pp. 14-6; also "Mechanical Improvements Planned in Iron Country Will Boost Output," *Engineering and Mining Journal*, Vol. 137, No. 2 (Feb. 1936), p. 111.

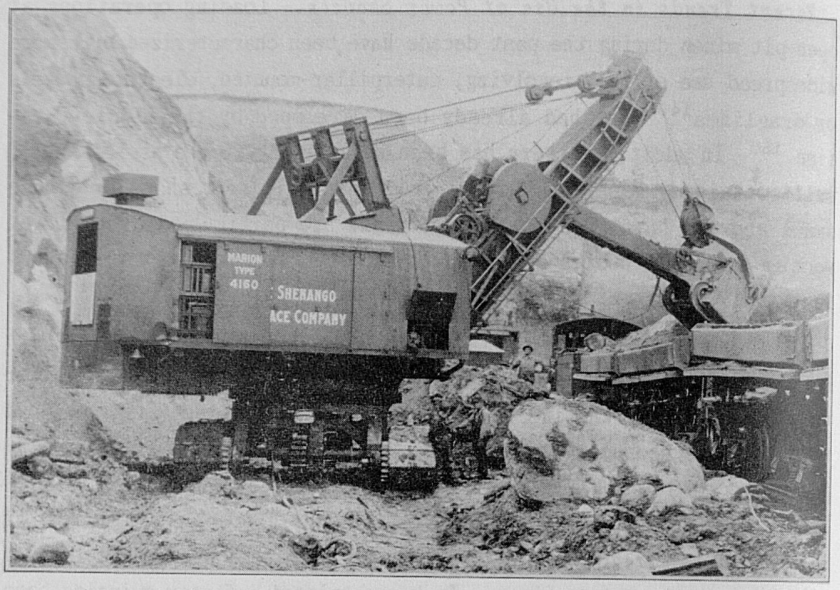




FIGURE 28.- MODERN POWER SHOVELS WORKING IN DIFFICULT GROUND

Powerful, sturdy, full-revolving, caterpillar-mounted, electric shovels such as these equipped with 4- to 5-cubic-yard dippers are among the most serviceable loading machines in use at iron mines. Despite some of the most difficult work in overburden containing large granite boulders and in frozen material, they dig rapidly and seldom break down. The loading efficiency and general mobility of power shovels increased so greatly in the post-war period that, despite a growth in the amount of ore produced from open-pit mines, there are fewer shovels in actual use today than 15 years ago.

growth in open-pit mining there are fewer shovels in actual use today than 15 years ago.[152] When almost all of the machines were steam-driven, railroad-type shovels equipped with railroad trucks, more units were needed than at present to load the same amount of material in the same length of time. Moreover, the task of moving the older shovels from place to place to load ore of the requisite grades was so laborious and time-consuming that it was often more economical to have several shovels stationed at different points in the pit, even though all shovels were not employed all of the time. More frequent shovel break-downs also necessitated keeping spare shovels on hand to reduce the amount of lost time.

Evolution of Open-Pit Haulage Techniques

The growth in the capacity and efficiency of haulage equipment paralleled the closely related increase in size and efficiency of excavating machinery. Improvements in the transportation system had to keep pace with the increased loading capacities of power shovels to secure the full benefit of the latter. The earliest power haulage equipment in stripping operations, for example, consisted of small dinkey locomotives weighing from 6 to 18 tons; small, hand-operated, wooden dump cars with capacities ranging from 1 to 6 cubic yards; and narrow-gauge, 36-inch track laid with lightweight rails.[153] Standard haulage equipment of present-day operations consists of powerful steam locomotives weighing as much as 127 tons; steel automatic air-dump cars of capacities up to 30 cubic yards; and standard-gauge (4 ft.-$8\frac{1}{2}$ in.) track, laid with rails weighing from 60 to 110 pounds per yard.[154]

The Growth in Size and Efficiency of Steam Locomotives.- As previously observed, haulage power at the earliest mines was supplied by men or draft animals. Although horses were used to some extent to pull cars at open pits on the Mesabi range as late as 1903,[155] the general use of steam locomotives in open-pit mining began a few years before the present century. Small dinkeys with small hand-dump cars and light, narrow-gauge track were in common use in the early stripping operations and also to some extent in ore haulage. Like some modern switch engines, the dinkeys were without either cab or pilot wheels. This, plus their small size, enabled them to negotiate sharp curves easily. Many had

[152] Although it is not known precisely how many fewer shovels were used in 1937 than in 1924, for example, it is clear that there has been a substantial reduction. Compare table 13 and ftn. 145, p. 97.

[153] See Walker, *op. cit.*, p. 584; also Hunner, *op. cit.*, p. 4; also Thomas, *op. cit.*, p. 152; also Davenport, "Steam-Shovel Mining on the Mesabi Range," p. 404.

[154] See Taylor, *op. cit.*, pp. 791-2.

[155] Hunner, *op. cit.*, p. 4.





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[154] See Taylor, *op. cit.*, pp. 791-2.

[155] Hunner, *op. cit.*, p. 4.

water tanks "saddled" over their boilers to give greater weight over the drive wheels and therefore greater pulling power. The small dump cars could be readily pulled by the dinkeys and were easily dumped by hand. The lightweight, narrow-gauge track that had to be frequently moved on waste dumps could be shifted by relatively small gangs of men using aligning bars. However, with the increase in the size of power shovels to dipper capacities of 2 or more cubic yards and with the introduction of automatic compressed-air dump cars of 12-cubic-yard capacity, more powerful locomotives and standard-gauge track were needed. By 1914 such equipment was employed in all ore haulage and generally in stripping operations.[156]

Although the earliest locomotives used for hauling ore (weighing 45 to 70 tons in 1903)[157] were not so small as the dinkeys used in stripping work, they too were gradually replaced by more powerful and more efficiently designed engines. By 1924 a total of about 300 steam locomotives - ranging in size from 60 to 100 tons - were in use in the Lake Superior District.

Table 14.- NUMBER OF STEAM LOCOMOTIVES IN USE AT IRON MINES IN THE LAKE SUPERIOR DISTRICT IN 1924, BY SIZE[a]

State and range	Total	Size (tons)			
		60	70	80	100
Total, all ranges	298	83	149	41	25
Minnesota					
Mesabi	266	67	133	41	25
Cuyuna	13	4	9	-	-
Michigan					
Marquette	4	4	-	-	-
Gogebic	15	8	7	-	-

[a]Data from R. S. Walker, "The First Complete Electrification of an Open-Pit Iron-Ore Mine in Minnesota," *General Electric Review*, Vol. XXVII, No. 9 (Sept. 1924), p. 590.

At the present time the steam locomotives used at open pits range from the 60-ton, 0-6-0 type[158] to the latest heavy-duty switch engines of the 0-8-0 type that weigh 127 tons and are capable of hauling 1,000-ton loads on an adverse grade of $1\frac{1}{2}$ percent at a speed of 10 to 15 miles per

[156]C. M. Haight, "Steam Shovel Operation," *The Engineering and Mining Journal*, Vol. 97, No. 7 (Feb. 14, 1914), p. 359.

[157]Hunner, *op. cit.*, p. 4.

[158]This type, as indicated by the numbers 0-6-0, has six drive wheels but no cab or pilot wheels. The absence of cab and pilot wheels concentrates the weight of the locomotive on the drive wheels, giving it more tractive power and enabling it to negotiate sharper curves.

hour.[159] The most modern of the locomotives incorporate many features which have greatly increased their hauling efficiency and simplified their operation. Among these are the following: Superheaters that increase the force of steam by raising its temperature and reduce condensation in cylinders; piston valves that replace D-valves and save time and effort for repairs; cab-controlled cylinder cocks that provide a simple and quick means of draining water condensed in cylinders; cab-controlled flange oilers that enable the engineer to reduce friction between rails and flanges of wheels when rounding sharp curves; an improved power-reverse mechanism for quickly and easily reversing the locomotive; and tender boosters that give added power on upgrade hauls.

Not all pits, of course, are equipped with the largest or most modern locomotives. An important factor in increasing haulage efficiency has been the proper adaptation of haulage equipment to particular open-pit

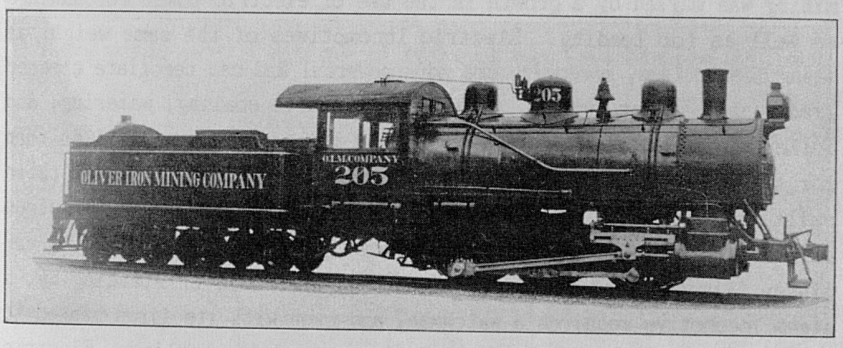


FIGURE 29.- OLD AND NEW STEAM LOCOMOTIVES AT A LARGE IRON MINE

Despite the trend toward the use of electric locomotives and trucks, the bulk of the material from open pits is still hauled out by steam locomotives, especially at large open pits where grades are not excessive. The power of steam locomotives has been gradually increased and their design improved, as is illustrated by the above photographs. The maximum tractive power of the earlier locomotives, built in 1910, was 28,700 pounds as compared with a maximum of 69,500 pounds of the later locomotives, built in 1927 and equipped with tender boosters and other modern improvements.

[159] See Taylor, *op. cit.*, p. 791; also "The Development of Earthmoving Machinery," *The Earth Mover*, Vol. 19, No. 12 (Dec. 1932), p. 11.

conditions. Grades must be carefully selected when the mine track is being planned. The boundaries of some pits are so limited that steep grades and sharp curves are required. For this reason switch engines of long wheel base may be ruled out and smaller locomotives must be chosen. The smaller locomotive is unable to handle so large a load on the steep grades, but it is less likely to go off the track on sharp curves. In some pits a geared-type locomotive has been chosen in preference to a rod-type because of its greater starting power and its ability to take sharp curves. The rod-type engine, however, is preferred on good tracks and grades of 3 percent or less because it is much faster, and most pits have been designed to accommodate such locomotives. Many companies have turned away from steam locomotives entirely and are employing electric locomotives and cars, gasoline or Diesel trucks, or belt conveyors.

Electrification of Open-Pit Haulage.- The post-war period in open-pit mining was marked by a growth in the use of electric power for haulage as well as for loading. Electric locomotives of the same weight as steam locomotives, moreover, are more powerful and can negotiate steeper grades and sharper curves. They do not require coaling, watering, and boiler cleaning, and their operation and maintenance cost is less than for steam units, despite the need to maintain trolley wires or third rails.[160] Although the operation of an electric locomotive requires only an engineer and brakeman, "steamers" need a three-man crew of engineer, fireman, and brakeman. Moreover, when idle or standing by, a steam locomotive requires a watchman, and even with its fires banked it still consumes 25 percent of the fuel required for hauling. Electric locomotives can be kept ready for operation without tending and consume no current when idle. The increased efficiency of 75-ton electric locomotives over their 70-ton steam predecessors at the Hill-Annex pit, at present the largest electrified iron mine, is clearly indicated by the following statement:

> The steamers could only haul five 75-ton loaded cars up a 2% grade against six cars of the same size for the electrics. Even with five cars the steamers had to have a running start to negotiate the 2% grade, and for perhaps 30% of the time had to back up for a fresh start. The situation was aggravated when the rails were wet or slippery. The maximum speed of the steamers while hauling five cars up a 2% grade was 8 miles per hour, and the electrics can easily haul six cars from a standstill and attain a speed of better than 10 miles per hour.

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[160] In one instance the total operating and maintenance cost per locomotive-shift was computed to be about half that of steam locomotives. (See Walker, *op. cit.*, p. 590.) In another instance the maintenance cost of locomotives was found to be 75 percent of the maintenance cost for steam locomotives of about the same size. See *Skillings' Mining Review*, Vol. 26, No. 44 (Feb. 26, 1938), p. 2.

> The benefit of this is very apparent. For example the distance from the working cut to the ore-yards is 3 miles. It would require the steamers $22\frac{1}{2}$ minutes to haul 375 tons that distance, or $16\frac{2}{3}$ tons per minute. The electrics will haul the same distance, 450 tons in 15 minutes, or 30 tons per minute. The electrics are therefore hauling 1.8 times as much ore as the steamers in a given time.[161]

Electric locomotives were not introduced in open-pit iron mining in the Lake Superior District until 1924.[162] One of the deterrences to their earlier adoption was their high initial cost. In the past 15 years, however, the price of electric locomotives has declined in relation to that of steam units.[163] Moreover, electric-power rates in the vicinity of the Mesabi range have also come down while the price of coal has risen.[164] These factors have increased the relative economic advantage of electric equipment and have hastened its adoption. At least 11 open-pit mines at the present time have partly or fully electrified haulage systems.[165]

These mines have a variety of types of electric haulage equipment. The locomotives range in size from 10 to 75 tons, depending upon the particular haulage problems encountered. Three of the operations - the Susquehanna, the Wakefield, and the Shenango mines - have become so deep that it has been necessary to haul cars to a shaft, transfer the loads into skips, and hoist them, as in underground mining.[166] The Susquehanna and the Wakefield mines employ motorized locomotive cars. (See figure 30.) Such locomotives themselves carry an ore load, in addition to pulling a train of loaded cars. The added weight of the ore load on the drive wheels of the locomotive gives it greater tractive power when it is most needed; and on the return journey, when the train of cars is empty and less tractive power is needed, the weight on the drive wheels is less, with a consequent economy in power consumption.

The Volunteer mine in Michigan uses a novel system of electric haulage by remote control. The movement of the motorized cars is controlled from a central tower commanding a view of the entire haulage system.

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[161] *Skillings' Mining Review*, Vol. 26, No. 44 (Feb. 26, 1938), p. 2. See also L. C. Moore, "Open-Pit Transport on the Mesabi Range - II," *Engineering and Mining Journal*, Vol. 139, No. 11 (Nov. 1938), pp. 52-4.

[162] A. H. Hubbell, "Open-Pit Mining," *Engineering and Mining Journal*, Vol. 132, No. 10 (Nov. 23, 1931), pp. 443-4.

[163] Moore, "Open-Pit Transport on the Mesabi Range," p. 47.

[164] See *U. S. Steel News*, Vol. 2, No. 6 (June 1937), p. 18.

[165] These include the Wabigon, Mesabi Chief, Susquehanna, Hill-Annex, Shenango, Hawkins, and the Merritt-Louise mines in Minnesota, and the Volunteer, Richmond, Tilden, and Wakefield mines in Michigan. Almost all of these mines employ some electric shovels, and several other mines use electrically operated belt conveyors and scrapers.

[166] See Hubbell, *op. cit.*, pp. 443 ff.; also Moore, "Open-Pit Transport on the Mesabi Range," p. 45; Hunner, *op. cit.*, pp. 16-9; and Barber, *op. cit.*, p. 8.

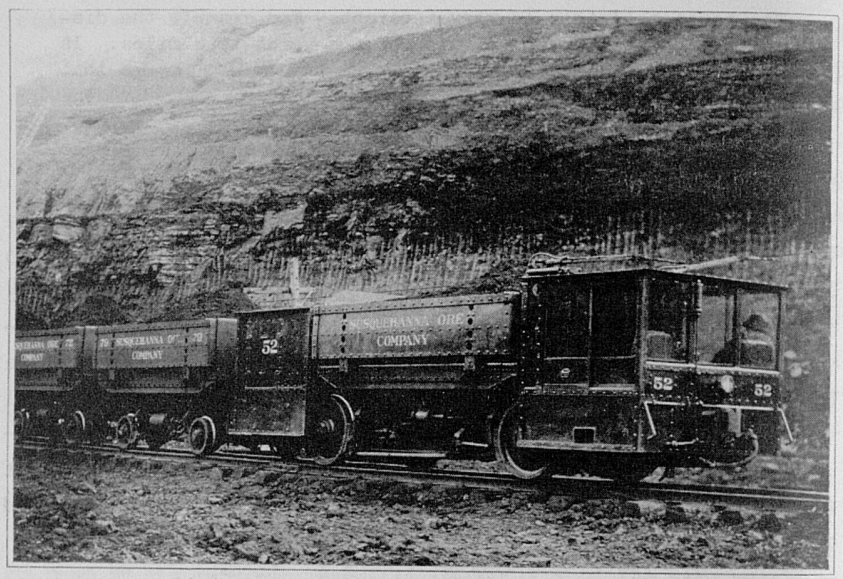


FIGURE 30.- COMBINED ELECTRIC LOCOMOTIVE AND DUMP CAR

By carrying a load of ore, locomotives of this type secure added weight for the tractive effort needed to pull a loaded train. On the return trip, after unloading, the locomotive is lighter and its tractive effort is reduced at the time that less effort is required. Ballast is unnecessary, with a consequent saving in current consumption.

Such a system obviously reduces labor requirements for transportation service.[167] Moreover, the cars, which are equipped with a motor on each axle, negotiate adverse grades as high as 8 or 10 percent.[168]

With greater haulage difficulties resulting from increasing depth of workings, these and many other haulage systems will probably be adopted at other operations. Mine operators contemplating a change in their haulage system have the benefit of the experience of the pioneers, and the newer installations will doubtless be improved by correcting imperfections revealed by past experience.

Improvements in Haulage-Car Design.- The evolution in the size and design of haulage cars has accompanied improvements in power shovels and locomotives. Open-pit mines are equipped with two general types of cars: ore-shipping cars and dump cars. Ore-shipping cars are used to carry ore from the mines or from the beneficiating plants, and are usually owned by railroads that haul them to ore-shipping docks where they

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[167] "With this system the only haulage operating labor consists of one man in the central control tower, one man on the shovel for spotting cars for loading, and one man in the crushing plant for spotting and dumping the loads, as made available, into the crusher." See A. C. Butterworth, "Electric Power in Lake Superior Iron Mining, and Its Influence on Output," *Engineering and Mining Journal*, Vol. 126, No. 23 (Dec. 8, 1928), p. 903.

[168] See A. H. Hubbell, "Open-Pit Mining - II," *Engineering and Mining Journal*, Vol. 132, No. 11 (Dec. 14, 1931), p. 486; also Moore, "Open-Pit Transport on the Mesabi Range," p. 45.

are emptied from the bottom into the ore-dock pockets. The other type of haulage car dumps to one or both sides. These are not so high as the standard ore cars and are used to haul overburden or lean ore to waste dumps or stock piles and crude ore to beneficiating plants.

Both types of cars have been vastly improved in the past half-century. The first ore-shipping cars used in iron mining were built of wood and had ore-carrying capacities of 20 to 30 tons. Around the turn of the century, 50-ton steel cars were introduced, and in the post-war period many 75-ton and some 85-ton cars were adopted;[169] successively better cars also came into use. Their size was increased to meet the needs of larger power shovels and increased production; their riding ability over rough mine track was improved through better balancing; and improved brakes have increased their ability to stop on steep grades and, together with better draft gear, have increased their adaptability for haulage in long trains.

The improvement in dump cars has been even more striking. Up to about 1913-14 all cars were dumped by hand.[170] For this reason their size was limited, ranging from the 1-cubic-yard cars that ran on narrow-gauge track and were hauled by horses or dinkeys to the 7-cubic-yard cars that were designed for standard-gauge track and for larger (about 50-ton) locomotives. Safe dumping of one of the larger cars required two or three men.

A revolutionary change was brought about by the introduction of the automatic dump car. This development, which occurred just prior to the World War, not only permitted a large increase in the size of dump cars and thereby facilitated loading by shovels with larger dipper capacities, but also eliminated the large crews of men formerly needed to dump the cars by hand and to right them afterward. The first automatic side-dump cars had a capacity of 12 cubic yards and were dumped by air-actuated cylinders controlled simply by turning or pulling a hand lever. These were soon followed by 16- and 20-cubic-yard air-dump cars for use with the large shovels introduced during the war period. After the war many operators also adopted 25- and 30-cubic-yard cars, which have now become standard.[171]

The efficiency of dump cars has also been increased through improved design and construction. Early side-dump cars were hinged at the top,

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[169] See Taylor, *op. cit.*, p. 792.

[170] *Ibid.*, p. 791, see also Davenport, "Steam-Shovel Mining on the Mesabi Range," p. 404.

[171] An order was recently placed with the Bethlehem Steel Corporation for automatic air-dump cars of 40-cubic-yard capacity to be used at the Cornwall iron mine in Pennsylvania. See *Skillings' Mining Review*, Vol. 27, No. 8 (June 18, 1938), p. 8.

often interfering with their dumping ability. The material had to be deposited too near the dumping track, thereby increasing the labor necessary for cleaning off tracks and shoveling dirt away from them. Moreover, large lumps of material often lodged between the car bottom and the top of the door. Modern cars have apron doors hinged at the bottom so as to avoid these difficulties.[172] The latest cars are more sturdily constructed to withstand the hard wear to which they are subjected. (See figure 31.)

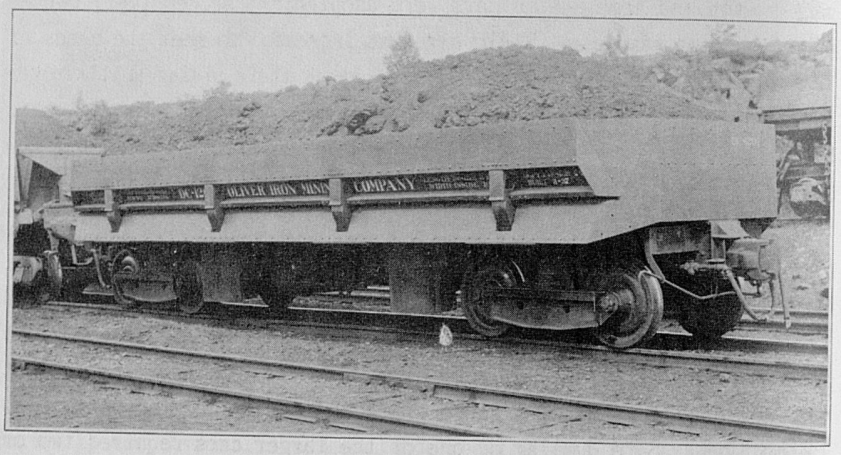


FIGURE 31.- A MODERN AUTOMATIC DUMP CAR

Automatic dumping of cars used for hauling overburden or for transporting crude ore to beneficiating plants has permitted a large increase in their size. Such cars have not only eliminated large crews of workmen formerly needed to dump the cars by hand and to right them afterward, but also have facilitated loading by power shovels with larger dipper capacities.

Modern side-dump cars are sturdily built and have a capacity of 25 to 30 cubic yards. They are tipped and righted by powerful compressed-air cylinders and have apron doors hinged at the bottom. Their dumping action is powerful and quick, and the load is deposited at a suitable distance from the track.

Lowering the center of gravity of dump cars has resulted in greater stability while riding, and especially while the car is being dumped. One of the difficulties in handling dump cars in winter results from the freezing of the moist material into a mass which sticks to the cars. When the cars are dumped, the heavy solidified load sometimes carries sufficient force to pull the car off the track. Cars built with a lower center of gravity cannot be so easily dislodged from the track as other types.

The weight of modern dump cars has been reduced as much as one-third by improvements in car design and by the use of higher-strength, lighter-weight, alloy steel bars and plates.[173] In this way the proportion of

[172] Taylor, *op. cit.*, p. 791.

[173] Moore, "Open-Pit Transport on the Mesabi Range," p. 44.

pay load to gross weight has been increased without adding to power requirements for haulage.

Improved Methods of Track Laying in Pits.- Track work is of vital importance to the smooth and efficient operation of open-pit haulage. The work of laying, shifting, and maintaining track in and about open-pit operations has always required a sizable part of the labor at open-pit mines.

Prior to about 1910 all temporary loading track in the pits was laid by hand. Ties were laid in the usual manner on hand-leveled ground, and the rails were spiked into position one by one. Today, all temporary track is built in the form of panels, rail-length long, and the track is quickly laid by large locomotive cranes.[174] Locomotive cranes could not be used for track laying until the practice of staggering rail joints - previously considered essential in railroad construction - had been abandoned. When rail joints are not staggered, rails often break in the vicinity of the joints, thus adding to the track-maintenance labor. It was found, however, that the resulting increase in maintenance work was not nearly sufficient to offset the large saving in labor made possible by the use of ready-built track sections handled by the large cranes.

Another outstanding improvement in track laying came about with the comparatively recent introduction of caterpillar tractors. Equipped with scraper or blade attachments and variously known as bulldozers, angle-dozers, or road builders, these units are widely used for smoothing out the ground prior to track laying and for shifting, lining, and ballasting track. In fact, tractors are now employed for a large variety of odd jobs at open-pit operations, not only for building and maintaining haulageways but also for such tasks as cleaning overburden from the top of the ore body and gathering up the ore remaining at the bottom of the pits. Much of this work had formerly been done with hand labor.

Labor Economies at Waste Dumps.- The last 20 years have witnessed important economies in the handling of waste materials excavated from open pits. As has been noted, the use of large, automatic, air-dump cars, easily controlled from the locomotive cab, has eliminated crews previously needed to dump the cars by hand and to right them afterward. Powerful dump spreaders and track-shifting machines have replaced other large crews.

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[174] See Taylor, *op. cit.*, p. 792. Prior to 1910 locomotive cranes were used for other purposes, but temporary tracks were all laid or shifted by hand.

Stripping or lean-ore dumps are usually started by erecting a trestle to support the first track. When the dump has been built up to the top of the trestle, it is necessary to level the dump and shift the track to a new position close enough to the edge of the pile to allow for the dumping of additional cars. Twenty-five years ago much of the dump spreading and all of the track shifting were done by hand labor. In the earlier days, when lightweight, narrow-gauge track was used, a single dump crew of about 9 men was sufficient for cleaning and shifting track; with the introduction of standard-gauge equipment and heavier rails, one crew was employed to clean off the track and another crew of 14 to 22 men to shift it.[175]

The dump spreaders or plows eliminated the shovel crews and also kept the dumps in better condition for track moving. Locomotive-propelled dump spreaders used for this purpose vary from home-made devices built around the trucks of an old 7-yard dump car - loaded with scrap rails for added weight and having a spread of only about 5 feet - to the large, specially constructed plows which, weighing 70 tons and having a dual set of wings operated by compressed air, are capable of leveling in one

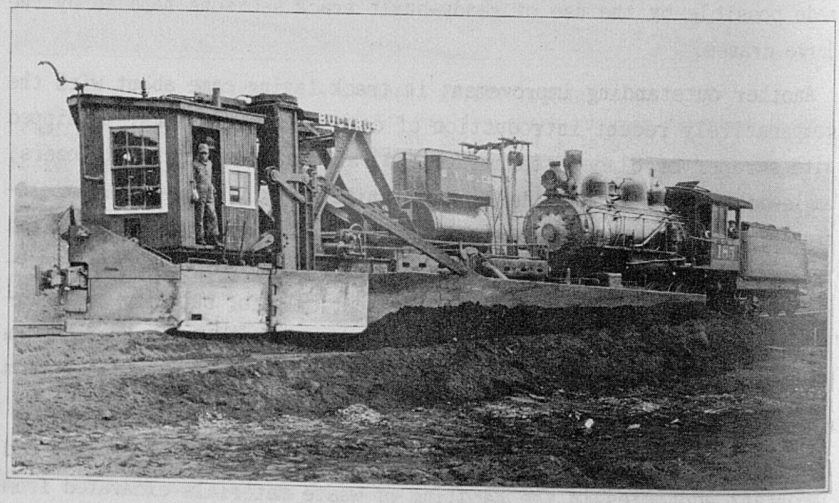


FIGURE 32.- DUMP SPREADER USED AT OPEN-PIT MINES

The heavy, locomotive-propelled plow shown is used on waste dumps near open-pit mines to level and spread dumped material. Such a plow, weighing 70 tons and having a dual set of wings operated by compressed air, levels a swath 22 feet wide with one sweep. It can plow 24 inches below the rail, thus providing room for the dumping of large-capacity cars.

The introduction of the spreader plow has been a large factor in reducing labor requirements at open-pit mines, replacing hand shoveling and reducing the amount of track shifting on dumps.

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[175] In dry weather, 60-pound track could be thrown by a 14-man crew using track-aligning bars. In wet weather and heavy work in sticky ground, however, up to 22 men were needed. See van Barneveld, *op. cit.*, p. 135; also L. D. Davenport, "Steam-Shovel Mining on the Mesabi Range - II," *Engineering and Mining Journal*, Vol. 105, No. 11 (Mar. 16, 1918), p. 495; also Fay, *op. cit.*, p. 420.

sweep a swath 20 to 30 feet wide and 18 to 24 inches below the rail.[176] (See figure 32.) The work accomplished by one of the larger dump spreaders with a crew of only 2 men is equal to that formerly performed by a dump crew of about 50 men.[177]

Specially designed machines that shift dump tracks without disconnecting them also radically reduced the number of men required for track shifting. A crane type of shifter with two booms, first used in 1916, required but a few men to operate it and did as much work as 40 or 50 men.[178] The one-man Nordberg type,[179] introduced in the post war period, could do the work that formerly required a crew of 14 to 22 men. (See figure 33.)

Special track-shifting machines, however, are used only at the largest stripping operations. They have not been generally adopted because they are specialized equipment unsuitable for other work. For most small track-shifting jobs which occur at various times during the shipping season when nonmerchantable materials are encountered and must be removed to the dumps, the ordinary locomotive crane is used, as in the pits. Bulldozers have also been used for work on dumps.

Of course, much track-laying and track-shifting labor in the pits was eliminated by the introduction of improvements that reduced the amount of this work necessary. Among these were the adoption of caterpillar traction on power shovels; the use of larger shovels that reduced the number of necessary cuts and that could load cars spotted on levels above them; the use of electric locomotives that could negotiate steeper grades; and, finally, the recent introduction of truck or tractor haulage and belt conveyors that not only reduced the length of haulageways but also eliminated all need for laying track on them. Even in the period from 1924 to 1931, before the most recent improvements and after the major developments of the wartime decade, the relative importance of trackmen at open-pit mines declined substantially, from 23.5 to 19.4 percent of the total employees.[180]

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[176] Davenport, "Steam-Shovel Mining on the Mesabi Range - II," p. 496.

[177] Davenport, "Steam-Shovel Mining on the Mesabi Range," p. 404.

[178] This machine, resembling a wrecker, had a 40-foot boom that lifted the track with ties attached while another boom on the level with the base of the machine moved the track sideways. The machine could throw track 4 to 6 feet to one side at 30-foot intervals. See L. A. Rossman, "A Useful Track Shifter," *Engineering and Mining Journal*, Vol. 102, No. 22 (Nov. 25, 1916), p. 940.

[179] This type of machine is equipped with a spud that, when lowered, raises the track and the machine clamped to it. Then, by changing the angle of the spud, the operator is enabled to move the track a short distance to one side and lower it. This process is repeated every few feet until a sufficient length of track has been moved the desired distance.

[180] Not including pitmen engaged in laying track sections for railroad-truck-mounted shovels. (See table A-15.)

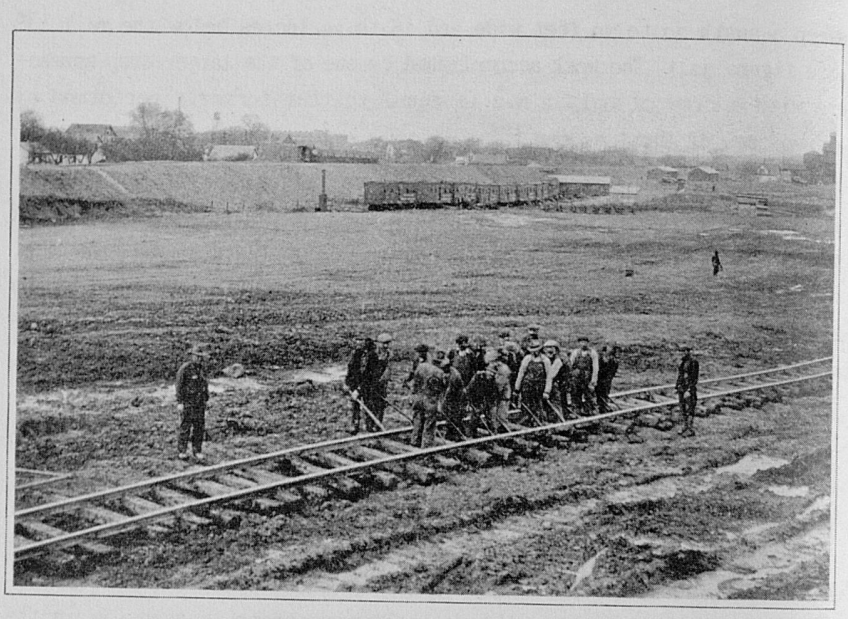




FIGURE 33.- OLD AND NEW METHODS OF TRACK SHIFTING

A modern one-man track shifter, such as shown in the lower view, can now do the work that formerly required a crew of from 14 to 22 men. Tracks on waste dumps are also shifted economically (without disconnecting them) by a crane-type shifter equipped with two booms; one boom raises the track vertically while the other moves it horizontally. Another effective method of track shifting widely employed at open pits uses wrecker cranes, each equipped with one boom, which move disconnected rail-length sections consisting of the two rails with ties attached.

Belt Conveyors.- Belt-conveyor haulage in iron mining has developed well within the past decade and promises to play a more important role in the future. The successful large-scale application of belt conveyors at the Grand Coulee Dam in the Pacific Northwest in 1935 doubtless indicated to iron-mine operators the possibilities of this method.[181] At least seven iron mines have installed belt-conveyor systems within the past few years.[182]

A conveyor belt is one of the most efficient means of moving loose materials. As much as 95 percent of the total load is pay load, and only a small percentage of the horsepower is required to run the empty belt. With trucks, the pay load varies from 60 to 70 percent; it is nearly the same for locomotives. Belt conveyors require shorter haulageways, for they can operate on much steeper grades than locomotives or trucks. A conveyor belt hauling iron ore, for example, can operate on maximum grades as steep as 32 percent, thus elevating the material 10 times as rapidly as by steam locomotives and 2 or 3 times as rapidly as by trucks. In long belt systems, where the material must be transferred from belt to belt at various angles, a man is needed at each transfer point. Additional beltmen are required for keeping the idler pulleys oiled and for cleaning the belts when handling sticky ore. Despite this, however, belt conveyors permit great labor saving in eliminating track laying and maintenance and locomotive operation.

The most important effect of belt conveyors, however, is in mining ore that cannot be hauled out of the pits with locomotives. With railroad haulage, as mines go deeper, more track must be laid and maintained. Also, more ore is tied up in track benches and cannot be mined until the tracks are removed. To mine this ore, some operators have had to sink shafts and to hoist the remaining ore, with a consequent lower output per man. Belt conveyors, however, may be installed at the bottom of or underneath an ore body so as to tie up a minimum quantity of ore.

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[181] Material from the excavations at the Grand Coulee Dam was successfully conveyed over a 2-mile network of 60-inch conveyors to a dump a mile away. The total lift was over 500 feet. See "Equipment Under the New Deal," *Engineering and Mining Journal*, Vol. 137, No. 2 (Feb. 1936), p. 97.

[182] These include the following open-pit mines: St. Paul, Spruce, Dale, Canisteo, and Judd pits in Minnesota, and the Millie mine in Michigan. The La Rue mine in Minnesota is an underground mine equipped for belt haulage. See David N. Skillings, "New System of Mining at the St. Paul Iron Ore Property," *Skillings' Mining Review*, Vol. 25, No. 30 (Nov. 21, 1936), p. 1; also "New Belt Conveyor System of Mining at the Spruce Mine Delivers River of Iron Ore Running Up Hill Direct From Pit to Shipping Pocket," *Skillings' Mining Review*, Vol. 26, No. 25 (Oct. 16, 1937), p. 1; also Moore, "Open-Pit Transport on the Mesabi Range," p. 45; also news items in the following issues in Vol. 137 (1936) of *Engineering and Mining Journal*, No. 4 (Apr.), p. 206 and No. 6 (June), p. 305; also Charles H. Remer, "Judd Pit on Western Mesabi," *Engineering and Mining Journal*, Vol. 139, No. 3 (Mar. 1938), pp. 38-9; also David N. Skillings, "Millie Iron Mine Enters Shipping List," *Skillings' Mining Review*, Vol. 25, No. 22 (Sept. 26, 1936), p. 1; also Grover J. Holt, "Conveyor Transport in an Underground Mine on the Mesabi," *Engineering and Mining Journal*, Vol. 139, No. 1 (Jan. 1938), pp. 29-30, 52.

The largest belt-conveyor system used at present in iron mining is at the Spruce mine on the Mesabi range. It is interesting to consider how the use of this system has avoided haulage difficulties that would have been encountered had the conventional haulage methods been continued to mine the remaining ore, despite increasing depth. It was estimated that to reach the bottom of the ore body and to maintain the maximum permissible haulage grades would have required five additional switch-backs. A large amount of labor would have been necessary to lay and maintain tracks, and a large percentage of the ore under the haulage benches would have been inaccessible.

The haulage system at the Spruce mine embodies two other novel features, scrapers and trucks. Two tower excavators, 100 feet high, have been erected over the raises leading to the belt conveyors underneath the ore body. These towers are connected by cables to smaller, caterpillar-mounted anchor towers about 700 feet away. Scraper buckets between these towers are used to drag the ore to the raises. The operator in each of the two main towers has full control of the 3-cubic-yard scraper, the motor-driven anchor towers, and the rotation of the main tower on its circular track above the raise.[183] Track haulage is also avoided at the Spruce mine by the use of 20-ton trucks that haul ore to another raise leading to the belt conveyor underneath. The ore is crushed at each of the raises before being fed to the belt conveyor.

Motortrucks.- An important development in the past 2 or 3 years has been the growing use of large trucks or tractors for open-pit transport and dumping.[184] The trucks or tractors, together with small mobile and self-contained shovels, have opened up a new field of activity in the exploitation of small ore bodies near the surface that cannot be mined economically with standard railroad methods. Also, like belt conveyors, trucks now serve as a means of overcoming haulage difficulties resulting from increasing depth of mines. They are capable of hauling loads up relatively steep grades, thereby shortening the length of haul and minimizing the number of haulage benches. In the Louise mine in Minnesota, for example, the railroad haulage system that preceded the use of trucks necessitated an upgrade haul not exceeding 2 or 3 percent and 8,500 feet

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[183] A smaller scraper installation, roughly resembling the system at the Spruce mine, was successfully used as early as 1925 at the Miller open-pit mine on the Mesabi range. Its use secured the desired monthly output and reduced the number of men employed from 32 to 24. See L. C. Moore, "Pit Scraper for Loading Iron Ore," *Engineering and Mining Journal-Press*, Vol. 121, No. 16 (Apr. 17, 1926), p. 650. A scraper has also been employed for open-pit work in the Millie mine in Michigan. See Skillings, "Millie Iron Mine Enters Shipping List," p. 1.

[184] See, for example, Remer, *loc. cit.*; also David N. Skillings, "Motorized Haulage on Mine Stripping Operation of Wheeling Steel Corporation," *Skillings' Mining Review*, Vol. 27, No. 27 (Oct. 29, 1938), p. 1; also Moore, "Open-Pit Transport on the Mesabi Range," p. 45; also R. W. Whitney and Grover J. Holt, "Truck Haulage on the Mesabi and Cuyuna Ranges," *Engineering and Mining Journal*, Vol. 140, No. 1 (Jan. 1939), pp. 29-33.

long. Trucks that were able to negotiate grades up to 8 or 10 percent have shortened the haul to 3,185 feet.[185] Moreover, trucks or tractors are capable of working in cramped quarters and can go in and out of places that could not be reached with standard railroad methods. Shorter haulage systems and more flexible haulage equipment mean speedier transportation and more complete extraction of ore.

Although small, standard road-type trucks equipped with dump bodies had been used at several open-pit mines prior to 1937, the specially designed, large, fast, heavy-duty trucks were introduced in 1937.[186] Many open-pit operations are now using pneumatic-tired trucks or tractor-drawn, self-dumping wagons, designed for a variety of special needs and ranging in size from 2 to 20 tons.[187] (See figure 34.) Many aspects of this development are still in the trial stages, as gasoline and Diesel engine-driven units, 6-wheel and 10-wheel types, trucks and tractors, large and small units, and other types of alternative equipment are being tried out at different mines. The performance of machines now in use and of newly designed units being continually offered by manufacturers is closely studied, and it is anticipated that still better equipment will be evolved; its wider use may be reasonably predicted.

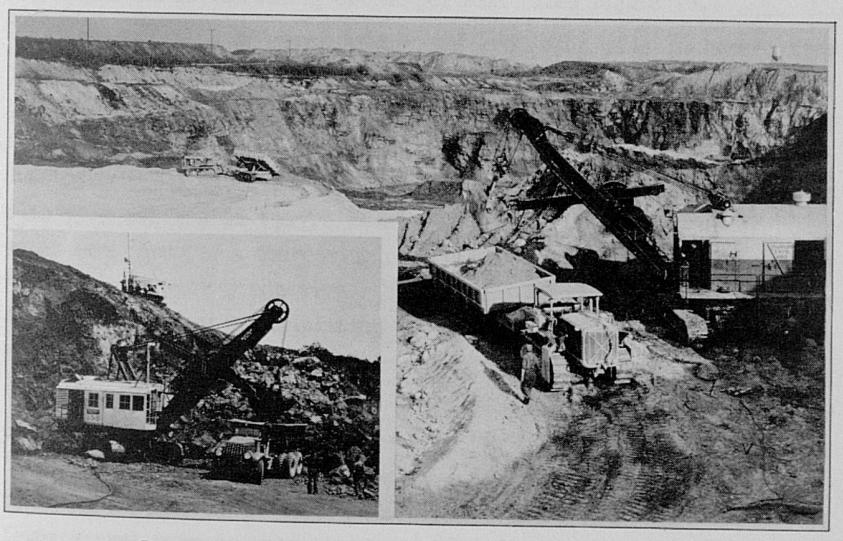


FIGURE 34.- HAULING WITH TRUCKS OR TRACTOR WAGONS

An increasing number of open-pit mines are employing trucks or tractor wagons to overcome haulage difficulties resulting from deeper mining. Trucks and tractors are capable of hauling loads over relatively steep grades, thereby reducing the length of haul and the number of necessary haulage benches. Unlike locomotives, they can work in relatively cramped quarters and require no track laying.

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185 Whitney and Holt, *op. cit.*, pp. 30-1.

186 *Ibid.*, p. 29.

187 Among the open-pit mines in Minnesota employing trucks or tractor wagons are the following: Dale, Louise, Spruce, St. Paul, Wacootah, and Judd.

Improvements in haulage techniques in and about open-pit mines have been directed toward bringing about the complete coordination of digging and haulage so that the mining of ores of proper grades could proceed smoothly and efficiently. This has involved the planning of operations well in advance. Operators had to develop an intimate knowledge of the nature and disposition of ores in the properties with which they were concerned. They had to acquire a thorough familiarity with all the machinery used in their mines and also to keep an eye on the development of new types of machinery that had a bearing on their work. Shovels had to be adequately supplied with cars at all times, and loading track had to be in place in time for production. Equipment and haulageways, especially the strategic points in the track lay-out, had to be kept in good condition to avoid major tie-ups. Efficient mine operation therefore involved much more than the introduction of new machinery. Proper planning and supervision have also had an important influence on the rise in output per man.

CHAPTER V

CHANGES IN LABOR REQUIREMENTS AND TECHNOLOGY AT UNDERGROUND MINES*

Although underground iron mines have produced about half of the total output of iron ore in the past 23 years, they have accounted for about three-fourths of all the employees in the iron-mining industry. As previously observed, average output per man at underground mines during this period was about one-third as high as at open-pit operations.

CHANGES IN EMPLOYMENT, PRODUCTION, AND PRODUCTIVITY

Employment at underground mines has declined sharply from a peak of 45,203 men in 1917. The post-war high was 28,242 men in 1923; in 1929, 22,242 men were employed, and 16,760 in 1937. In the latter year - one of large production - employees at underground mines made up 65 percent of the total for both types of mines. The average number of workers employed in 1937 represented a decline of 63 percent from 1917, 41 percent from 1923, and 24 percent from 1929. The general downward trend of employment at underground operations is the net result of a declining production and an increasing output per man. (See figure 16.)

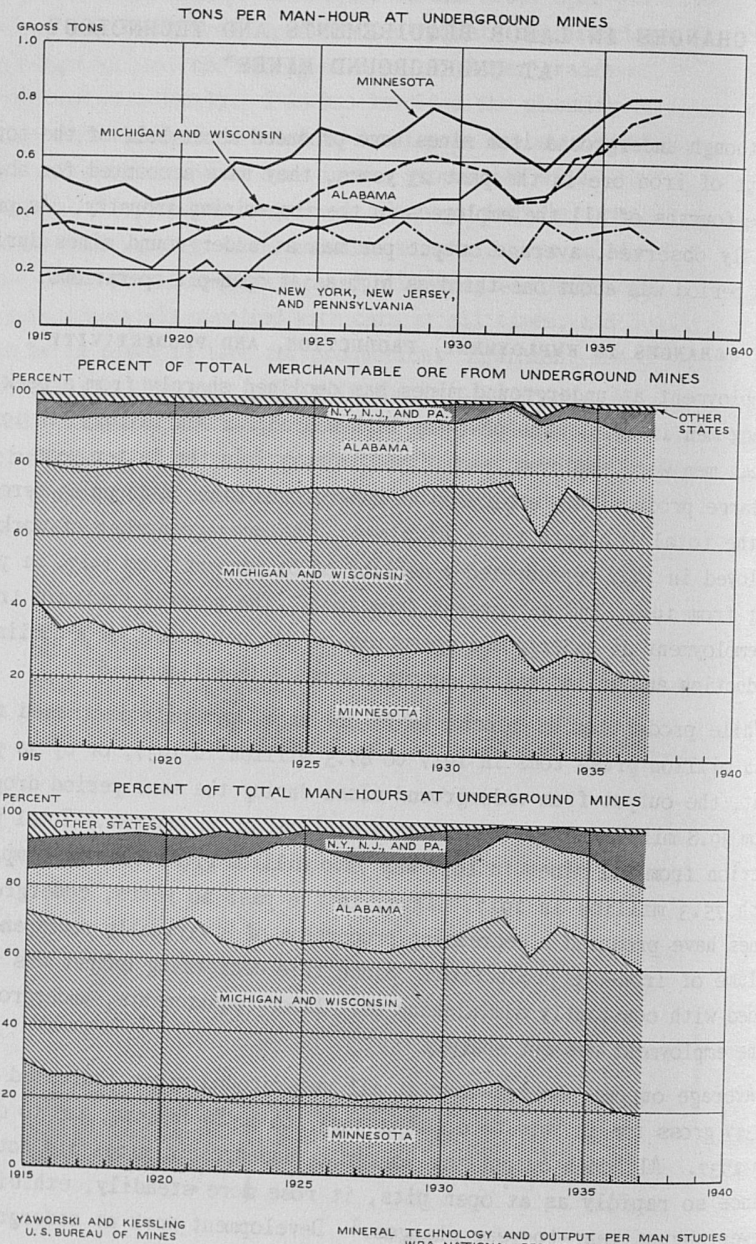
While production of merchantable ore from open pits increased from 35.4 million gross tons in 1917 to 47.5 million in 1937, or by 34 percent, the output from underground mines during the same period dropped from 39.8 million gross tons to 24.6 million, or 32 percent. Total production from all mines in 1937 was 72.0 million gross tons as compared with 75.3 million in 1917. Thus, in the past 20 years, underground mines have produced a decreasing proportion of a virtually nonexpanding volume of iron-ore production. Since this decreasing output was produced with constantly diminishing unit labor requirements, underground-mine employment was cut sharply.

Average output per man-hour at all underground mines increased from 0.347 gross ton in 1917 to 0.408 in 1923, to 0.589 in 1929, and to 0.692 in 1937. Although output per worker at underground mines did not advance so rapidly as at open pits, it rose more steadily, exhibiting fewer abrupt year-to-year changes.[1] Development work at underground

*By N. Yaworski, O. E. Kiessling, C. H. Baxter, and Lucien Eaton. As noted on pp. 120 and 141, the section entitled "Evolution of Underground-Mining Methods" was prepared by C. H. Baxter, and the section entitled "Progress of Underground Transportation" by Lucien Eaton.

[1]The range in output per man-hour among individual open-pit mines was about five times as large as among underground mines. (See table A-18.)

Figure 35.- OUTPUT PER MAN-HOUR AND PERCENTAGE OF TOTAL PRODUCTION AND MAN-HOURS AT UNDERGROUND MINES IN PRINCIPAL IRON-ORE-MINING STATES, 1915-37



YAWORSKI AND KIESSLING
U. S. BUREAU OF MINES

MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES
WPA-NATIONAL RESEARCH PROJECT E-236

During the past 23 years Minnesota produced 32 percent of the total underground production with 24 percent of the total man-hours because the average man-hour output, 0.58 gross ton, was considerably higher than in other States. Michigan and Wisconsin accounted for 44 percent of the total production with an average man-hour output of 0.44 gross ton. Underground mines in Alabama produced 18 percent of the total, and those in New York, New Jersey, and Pennsylvania 4 percent, with average man-hour productivities of 0.37 and 0.23 gross ton respectively. (See table A-6 for data.)

mines was more evenly distributed in relation to production, and total output fluctuated less widely.

In the past score of years for which data for underground mines could be segregated, average output per worker increased in all important areas. (See figure 35.) Three-fourths of the total output of underground mines was produced in the Lake Superior District, where the output per man-hour was much higher than elsewhere. Michigan and Wisconsin produced 44.1 percent of the total underground output at an average rate of 0.444 gross ton per man-hour; Minnesota, with the highest man-hour productivity of 0.580 gross ton, accounted for 31.7 percent of the total. Among the remaining States, Alabama produced 17.9 percent of the total; New York, New Jersey, and Pennsylvania, 4.1 percent; and all other States, 2.2 percent. The average output per man-hour in these areas was 0.373, 0.232, and 0.222 gross ton respectively.[2] (See table 15.)

The growth in output per worker at underground mines in the past 20 years is a continuation of a trend that characterized the previous 30 years. Although separate data for underground mines are not available

Table 15.- AVERAGE ANNUAL INCREASE IN OUTPUT PER MAN-HOUR AT UNDERGROUND IRON MINES IN PRINCIPAL AREAS, 1915-37[a]

Area	Average annual increase in man-hour output[b] (gross tons)	Average output per man-hour (gross tons)	Percent of total underground production
United States, total	0.016	0.436	100.0
Michigan and Wisconsin	.017	.444	44.1
Minnesota, total	.014	.580	31.7
Mesabi and Cuyuna ranges	.019	.620	26.9
Vermilion range	.012	.426	4.8
Alabama	.017	.373	17.9
New York, New Jersey, and Pennsylvania	.010	.232	4.1
All other States	(c)	.222[c]	2.2

[a] Data from table A-6.

[b] Computed from a trend line fitted by the method of least squares.

[c] Data represent mines in a large number of States, many producing iron ore very irregularly. The average annual increase in output per man is therefore of little significance and is omitted from the table.

[2] The employment data on which these computations are based included all employees (wage earners) at the mines - those employed underground as well as those in surface shops and beneficiating plants.

for the longer period, the trend is indicated by the rapid growth in average output per man at all mines in areas where underground mining predominated. For example, average output per man-shift in Michigan and Wisconsin advanced from 1.136 gross tons of merchantable ore in 1880 to 3.149 gross tons in 1915, or 177 percent. In New York, New Jersey, and Pennsylvania it increased from 0.832 gross ton to 1.710 gross tons, or 106 percent. (See table A-4.)

To some extent the advance during the past half-century is ascribable to an increase in the proportion of the total underground output produced in areas with high output per man. The exploitation of easily mined soft-ore deposits of the Lake Superior District increased rapidly, while production from the hard-ore mines of New York, New Jersey, and Pennsylvania, where output per man has always been relatively low, dropped from 53 percent of the total in 1880 to about 4 percent at the present time. (See figure 12.) That this is only a partial explanation, however, is indicated by the fact that output per man continued to rise at individual mines despite difficulties that accompanied depletion.

EVOLUTION OF UNDERGROUND-MINING METHODS*

The advance in output per worker at underground iron mines in the past half-century is mainly attributable to a gradual succession of improvements in mining techniques. The latter have included the development and improvement of general systems of mining, or modes of attacking ore bodies, as well as progress in the mechanization of the specific functions of drilling, loading, and transporting materials. Apart from the utilization of more and better machinery, underground-mining methods have been gradually changed to reduce the amount of maintenance and development work, to utilize more fully the force of gravity for breaking and loading ore, to minimize the amount of timbering, to decrease interruptions in mining activities, and to make working conditions safer and healthier.

All of the basic mining systems or stoping methods[3] common to the art of winning minerals underground have been used in iron mining in the

*By C. H. Baxter, Head of Department of Civil and Mining Engineering and Economics, Michigan College of Mining and Technology, Houghton, Mich. As the section was prepared before all the statistical material was available in final form, rearrangement of the original manuscript to incorporate supplementary statistical data and to meet limitations of space was entrusted to N. Yaworski and O. E. Kiessling.

[3]Stoping is the term applied to the act of excavating ore by means of a series of horizontal, vertical, or inclined workings in veins or large, irregular bodies of ore, or by rooms in flat deposits. Stopes are simply the chambers from which the ore has been excavated. For an illustrated description of stoping methods, see Chas. F. Jackson and E. D. Gardner, *Stoping Methods and Costs* (U. S. Dept. [*Con.*]

past half-century, and each with many variations. These systems, distinguished principally by the method of supporting stopes, were either originally developed in iron mining or were introduced from elsewhere, chiefly between 1880 and 1895.

The choice of the most economical method requires much mining experience and technical and economic judgment since each ore body presents an individual problem. The method which permits maximum efficiency in one ore deposit may be entirely unsuited to another; and some ore deposits may be mined by one of several different methods. The mining engineer must consider the size, shape, and dip of the ore body. His choice is also influenced by its depth below the surface and its location with reference to drainage; by the uniformity of grade, by the hardness and friability of the ore; and by the strength and other physical characteristics of the enclosing wall rocks or capping. The choice of a suitable mining method may also turn on such economic factors as the availability of capital, the supply of labor, the cost of timber, and the demand for ore.

Although the basic features of the fundamental mining systems had been developed by about 1895, the methods now in use were greatly improved so as to adapt them better to natural conditions and new equipment. As a method was found that yielded satisfactory results in a particular type of ore body in each district, it was gradually adopted by other

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[3] [*Con.*] Int., Bur. Mines, Bull. No. 390, 1936), pp. 2 ff. The following classification of stoping methods has been adopted by the U. S. Bureau of Mines (p. 4):

"A. Stopes naturally supported.

1. Open stoping.
   (a) Open stopes in small ore bodies.
   (b) Sublevel stoping.
2. Open stopes with pillar supports.
   (a) Casual pillars.
   (b) Room (or stope) and pillar (regular arrangement).

"B. Stopes artificially supported.

3. Shrinkage stoping.
   (a) With pillars.
   (b) Without pillars.
   (c) With subsequent waste filling.
4. Cut-and-fill stoping.
5. Stulled stopes in narrow veins.
6. Square-set stoping.

"C. Caved stopes.

7. Caving (ore broken by induced caving).
   (a) Block caving; including caving to main levels and caving to chutes or branched raises.
   (b) Sublevel caving.
8. Top slicing (mining under a mat which, together with caved capping, follows the mining downward in successive stages).

"D. Combinations of supported and caved stopes. (As shrinkage stoping with pillar caving, cut-and-fill stoping with top slicing of pillars, etc.)"

operators; the details of its application were improved; and it became well established. A major change was made cautiously - only when it definitely promised greater efficiency. When such a change took place, as the substitution of top slicing for the square-set method, it had a large upward influence on output per man. Labor productivity was increased even more, however, by constant improvements in the established methods. This is indicated by a brief review of the evolution of mining methods in the three principal iron-mining areas - namely, the Northeastern District of New York, New Jersey, and Pennsylvania, the Birmingham District of Alabama, and the Lake Superior District. In the past quarter-century these areas produced 94 percent of the total production from underground mines.

Development of Mining Methods in the Northeastern States

Iron mining in the magnetite deposits of New York, New Jersey, and Pennsylvania dates back to pre-Revolutionary days. The evolution of mining methods over this long period of time enables us to gauge the acceleration of changes in the past quarter-century.

The mining history of New Jersey is divided by H. M. Roche[4] into three stages, the beginning of each period being marked by a complete change in the method of mining. For over a hundred years, from 1685 to 1800, the ore was taken from outcrops and mined in open pits. By 1800 the surface deposits had been exhausted and underground mining began.

In the next century, from 1800 to 1912, iron ore was crudely mined in open stopes by a method known as underhand stoping.[5] As the name implies, this is a method of working an ore body from the top down, and holes for blasting are drilled downward. Since the wall rocks necessitated timber supports, much oak and chestnut timber was used, and the adjacent countryside was virtually stripped of timber. Ore was trammed and sorted by hand. In the early part of the period it was hoisted in buckets by windlass or whim, and at some mines by water wheels with iron chains as hoisting ropes. Although power drills, steam pumps, and single-drum hoists increased the efficiency of the New Jersey mines toward the end of the century, they were unable to meet the competition from Lake Superior ores after 1882, and production declined rapidly.

The last period, since 1912, is marked by a revolutionary change in New Jersey mining methods. The iron-mining industry had reached a low

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[4] "The New Magnetic Concentrating Mill at the Richard Iron Mine, New Jersey - I," *Engineering and Mining Journal-Press*, Vol. 115, No. 21 (May 26, 1923), pp. 923-4.

[5] The method used at this time corresponds to the one called "Stulled stopes in narrow veins" in the classification given in ftn. 3.

ebb, and, unless improvements were made, it was certain that it would cease entirely. The largest mine in the district, employing 200 men, was producing only 30,000 tons of ore per annum. About this time the mine changed from open (underhand) stoping to shrinkage (overhand) stoping and also adopted electric haulage and double-drum hoisting.

In shrinkage stoping the stopes are advanced upward, the ore being removed in horizontal or slightly inclined slices. Only enough ore is drawn from the stope to afford working space to the miners, who stand on the broken ore and advance the stope upward while drilling. Since broken ore occupies more volume than ore in place, chutes closely spaced along the bottom of the stope draw off about 40 percent of the ore as it is broken. This method was found suitable to the physical conditions encountered in the steeply dipping (40° to 65°) magnetite veins. The broken ore afforded temporary support for the walls, and timbering was eliminated. Whereas the open stopes supported by timbers were dangerous, the shrinkage stopes were comparatively safe. Moreover, ore could be loaded into cars by gravity instead of by hand shoveling. As a result of these changes, the mine was able to increase its production to 300,000 tons of crude ore per year without increasing the number of men required. This represents a tenfold increase in output per man.

The first use of shrinkage stoping in New Jersey, as described by Mr. Roche, was at the Mt. Hope mine in 1912. Similar changes were made by the Washington mine in 1914, the Richard mine in 1916, the Scrub Oak mine in 1917, and the Beach Glen mine in 1920.[6]

A further change of method was made in 1931 at the Washington mine where shrinkage stoping was replaced by sublevel stoping.[7] The wide vein (80 feet) and the flat dip (43° to 45°) made shrinkage stoping difficult. In sublevel stoping a large section of the ore body between two main levels is excavated simultaneously at several sublevels which are connected vertically by openings called raises. Mining either begins at a raise at the extremity of the ore body farthest away from the shaft and retreats (progresses backward) toward the shaft, or it is commenced at a raise in the center of the ore body (as at the Washington mine) and retreats toward a raise at each end of the ore body. A bench is cut around the raise at each sublevel beginning at the lowest ore. As mining progresses, a single, large open stope is created, increasing in height to almost the distance between the two haulage levels. The

[6] Information obtained through correspondence with H. M. Roche, Consulting Engineer, Dover, N. J.

[7] C. H. Loux, "Mining Methods and Costs at the Washington Mine of the Alan Wood Mining Company," *Transactions of the American Institute of Mining and Metallurgical Engineers*, Vol. 109 (1934), pp. 51-60.

stope is widened from the bottom upward so that the workmen at each lower sublevel are protected from falling material loosened by miners working at the sublevel above them. The loosened ore is drawn off through chutes at the bottom of the stope.

In sublevel stoping as compared with shrinkage stoping, the miner works close to and under solid ground rather than under a fractured stope back. Moreover, he has a firmer footing, working on the solid ore and not on broken material. He is not delayed by ore being drawn from the stope. Since his work is close to the outlet from the stope, only the back above the bench on which he is working needs to be kept trimmed down. In shrinkage stoping, on the contrary, he may have to travel the length of the stope on broken ore and must keep the whole back free from loose material. Ventilation is generally better when sublevel stoping is used, for large open spaces permit a better circulation of air.[8]

Mining in the Lyon Mountain District of New York has passed through much the same stages as in New Jersey.[9] The early method was open (underhand) stoping with casual pillars for support. Shrinkage stoping was then adopted on the steeper deposits (the dip varies from 30° to 60°), and this was followed by sublevel stoping. Safety was the determining factor in the choice of sublevel stoping instead of shrinkage stoping on the steep deposits of this district.

Output per man has been raised in the Mineville District of New York despite the continuance of the open-stope method.[10] With the exception of one deposit now mined out, the deposits are relatively thin, varying from 3 to 40 feet in thickness, and extend from several hundred to several thousand feet in depth and laterally. They dip at angles of 20° to 30° from the horizontal. The firmness of the ore and overlying rock makes open stoping with casual pillars possible, but the flat dip prevents the use of methods employing gravity to load the ore into cars. The early operations were carried on with hand methods of drilling, shoveling, and tramming. These have been largely replaced by the use of air drills, scrapers, and mechanical loaders and electric haulage on the main levels. At present, furthermore, fewer shafts, of larger

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[8] Breaking cost at the Washington mine in 1931, because of improvements within the method, was 62.7 percent of that under the shrinkage-stoping system prior to 1929; the change to sublevel stoping further reduced the breaking cost to 44.2 percent. Costs of tramming and loading at chutes were reduced to 30.4 percent under shrinkage stoping, and to 14.0 percent under sublevel stoping. Approximately the same relationship would obtain if the cost compared were man-hour cost instead of money cost.

[9] Information obtained through correspondence with W. A. Blomstran, Mining Engineer, Lyon Mountain, N. Y.

[10] A. M. Cummings, *Method and Cost of Mining Magnetite in the Mineville District, New York* (U. S. Dept. Com., Bur. Mines, Inf. Cir. No. 6092, mimeo., Dec. 1928).

capacity, are used for hoisting, and the main haulage drifts[11] are driven at greater intervals. These changes reduced the cost of development and upkeep. The tonnage per man-day (of underground employees) increased from 3.47 in 1913 to 7.46 in 1927.

Improvement of Mining Methods in the Birmingham District

Although the red-ore beds of the Birmingham District in Alabama[12] have always been mined by open stopes with pillar supports, the system has been greatly improved in many details. The early method was called "drift mining" because the stoping consisted of widening drifts in the ore beds. The modern method is called "room-and-pillar" mining because there is a definite arrangement into rooms and pillars. In drift mining, development and stoping were carried on as one operation; with the room-and-pillar method, most of the ore is mined with rooms, where a greater division of labor is possible.

Mining in the red beds of this district involves winning a deposit of comparatively uniform thickness of 8 to 10 feet, dipping at angles of from 12° to 45° from the horizontal, with an average dip of about 20° which becomes flatter with depth. The upper portion of the bed, an average of 200 to 300 feet, was soft ore, the lime having been removed by atmospheric waters; below, the ore is of medium hardness and gives good support as pillars. There occur faults which interfere with the regular system and necessitate auxiliary hoisting and rehandling of the ore. An overlying water-bearing stratum necessitates the maintenance of the surface to avoid letting the water into the mines. Usually about 60 percent of the ore is extracted, and 40 percent is left in pillars. In a number of the large mines, however, only 30 percent is left unmined.[13]

When open-cut work became uneconomical, the development of underground mines by slopes and drifts was begun. Numerous short slopes were driven in the ore, and wide headings (entries or drifts in ore) were opened on either or both sides at intervals of 35 to 45 feet. No attempt was made to rob the pillars between headings, though upsets (raises) were made in them at intervals.

Improvements in mining methods have permitted an increase in output per worker despite mounting physical difficulties. When the hard ore

[11] Drift is the name commonly applied to horizontal underground passageways driven along the vein. Passageways driven across the vein from wall to wall are called crosscuts.

[12] W. R. Crane, *Iron-Ore (Hematite) Mining Practice in the Birmingham District, Ala.* (U. S. Dept. Com., Bur. Mines, Bull. No. 239, 1926).

[13] *Ibid.*, pp. 73-4.

was encountered, the same stoping method was continued, but power drills were substituted for hand-operated drills. As the workings were extended, economical operation required the elimination of many openings. A few of the old slopes were maintained, and new slopes were developed at more advantageous points. The distance between headings was increased, the width of the heading was either maintained or reduced, and a greater portion of the ore was mined from the floor pillars. Various methods were used in mining the ore between headings. Inclined branch tracks were used to bring the cars up the slope, and on steep dips switch-back tracks were necessary. On steeper inclines, shaking conveyors and gravity planes were also used. The development of the scraper has overcome the difficulty of handling ore on flat dips and has been a controlling factor in the more recent developments in mining these ores.

In the best modern practice[14] the amount of necessary maintenance and development work has been reduced by increasing the heading interval to 160 feet and more. At some mines the headings are first driven to the property line, and the ore is stoped out on retreat toward the shaft. This has avoided the upkeep of passageways in areas already mined out. Ore broken in the stopes is loaded directly into cars on the same level by means of scraper hoists and ramps or inclined planes which can be moved from stope to stope as loading is desired. This ore is trammed to the pockets at the slopes by electric haulage. Although most of the ore is still raised to the surface up slopes, the practice of hoisting the mine cars has been superseded by the use of automatic-dumping skips loaded from pockets and chutes.

The distance from the surface of the deeper active mines is from 6,000 to 9,000 feet along the slope, and their vertical depth is about 1,500 feet.[15] The increased depth has to some extent involved the use of more labor for maintenance of shafts, but this is of minor importance as compared with the reduction in the labor cost of mining. Improved facilities for taking men in and out of the mine have overcome the increased distance from the shaft collar to their working places.

Development of Mining Methods in the Lake Superior District[16]

The Lake Superior District, comprising the States of Minnesota, Michigan, and Wisconsin, produces over 70 percent of the total underground

[14] See E. M. Ball and A. W. Beck, "Iron Mining in Muscoda No. 6," *Engineering and Mining Journal*, Vol. 138, No. 9 (Sept. 1937), pp. 29-33 and a continuation of this article in Vol. 138, No. 10 (Oct. 1937), pp. 35-9; also Tenney C. DeSollar, "Iron Ore Mining on Red Mountain, Alabama," *Mining and Metallurgy*, Vol. 18, No. 371 (Nov. 1937), pp. 493-7.

[15] DeSollar, *op. cit.*, p. 496.

Footnote 16 appears on following page.

output of iron mines in the United States. Over two-thirds of the ore mined underground in this district is soft and amenable to the more efficient caving methods of mining. (See table A-22.) The years of the first important ore shipments from mines in each of the six ranges in the district are as follows: Marquette range, 1854; Menominee range, 1877; Gogebic range, 1884; Vermilion range, 1884; Mesabi range, 1892; and the Cuyuna range, 1911. The geologic conditions and the nature of the ore deposits in these areas vary greatly and have led to a wide variety of mining methods.

Early Stoping Methods.- Underground mining first began in the hard ores of the Marquette range about 1870-80 and, as in the earlier districts, was preceded by open-pit methods. The first underground operations were in open chambers not far below the surface. Where the ore bodies were too large to be mined out in single stopes, casual pillars were left to support the back. In some of the hard-ore mines on this range, the method of open stoping with pillar supports has continued, with variations, to the present time. Although the general method has remained the same, the elements making up the complete system of mining have changed greatly.

One of the oldest and largest hard-ore mines on the Marquette range using this method is the Cliffs Shaft mine at Ishpeming, Michigan.[17] The surface overlying the ore body is not caved because some of the mine workings underlie the city. The distance between levels[18] is 50 feet. Where conditions permit, rooms 25 feet wide and 25 feet high are driven by breast stoping,[19] and floors 25 feet thick are left between levels. The floors are mined by underhand stoping to raises. In the beginning of the latter operation the ore is blasted directly to the raise; when this is no longer practicable, the ore is dragged to the raise by scrapers. This method permits the sorting out of seams of poor rock.

The soft ores of the Lake Superior District presented a new problem in mining because the ore would not stand without support and had but little strength when left in pillars. In the hard-ore mines the only

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[16]Much of the information on iron-mining methods and practices in the Lake Superior District was derived from the author's personal experience and observation during the past 35 years. The author gratefully acknowledges information received from E. F. Brown, O. C. Davidson, John H. Hearding, F. A. Kelley, James MacNaughton, R. D. Parks, and O. M. Schaus.

[17]Lucien Eaton, *Method and Cost of Mining Hard Specular Hematite on the Marquette Range, Michigan* (U. S. Dept. Com., Bur. Mines, Inf. Cir. No. 6138, mimeo., May 1929).

[18]In mining it is customary to concentrate the handling of ore and the distribution of supplies on certain horizons called levels.

[19]In this method the working face is advanced horizontally in one or more vertical steps.

timber that had been used to support the back had been in props and rock-filled cribs; these proved inadequate on the soft ores. No method of support that was even moderately satisfactory was found until 1880, when square-set timbering[20] was introduced into the Vulcan and Chapin mines on the Menominee range. Shortly afterward it was used quite extensively throughout the Lake Superior District.

In this method the ground is supported by framed timbers which are built up from the bottom as the stoping progresses upward. The vertical members of each complete square set are called posts; the horizontal members, caps and girts. As the stope progresses upward, the posts of each succeeding set are placed directly upon the posts below. Since the cap is the strongest horizontal member, it is placed in the direction of the greatest horizontal pressure, from footwall to hanging wall[21] or from pillar to pillar. Sets are held in place by short blocks placed at corners and wedged tightly against the walls of the stope. By extending sets vertically and horizontally, this skeleton framework may be shaped to fit irregularly shaped stopes. When the ground is very weak, the stopes must be filled as well as timbered.

In the Michigan practice the ore body was usually laid out into rooms and pillars extending from footwall to hanging and from 2 to 6 sets wide, depending upon the nature of the ore. The posts were generally 7 or 8 feet in length; the caps and girts, 7 feet. These stopes were mined upward to within 15 or 20 feet of the level above. Sometimes, however, the stopes were much larger. If the ground held up well, the pillars between the rooms were mined out on square sets and the rooms connected horizontally. Occasionally the rooms were connected vertically. It was not unusual for stopes which had been enlarged too much to collapse.

Square-set stoping was almost the sole method of mining soft ores in the Lake Superior District until 1885, when top slicing was introduced. It was used extensively in the soft-ore mines of Michigan and also on the Mesabi range in connection with top slicing to mine ore that extended so high above the slicing level that it could not be mined in one slice. After 1890 the square-set method was of minor importance in iron mining, although in some mines it was continued until after 1920.

Although square-set stoping was much less efficient than the top-slicing or sublevel-caving methods that replaced it, its use under the

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[20] Developed in 1860 by Philip Deidesheimer at the Ophir mine on the Comstock lode in Nevada and known in Michigan as the Nevada System.

[21] In an inclined vein the lower wall is called the footwall and the upper wall is called the hanging or the hanging wall.

prevailing economic conditions permitted extraction of ore at a fairly low cost. When ore was reached, stoping could be started almost immediately without waiting for further development. This was a big advantage at a time when capital was scarce. Square setting required an enormous amount of timbering, but timber was plentiful and cheap. Although much labor was needed for timbering, the method permitted a saving of labor for loading, as most of the ore could be loaded from the stopes to the cars by gravity without shoveling. It was soon realized, however, that square sets did not provide permanent support. If a few timbers were thrown out of line, the entire framework was likely to collapse and endanger the workmen. Moreover, about 60 percent of the ore was left in pillars which could not be mined without expensive filling of stopes.

Top Slicing.- The top-slicing system of mining was developed in the mines of Lancashire, England, and introduced by English miners on the Marquette range in 1885.[22] This system proved so satisfactory in comparison with other known methods that it was soon generally adopted for mining the soft ores on the Marquette and Gogebic ranges in Michigan, and later on the Vermilion, Mesabi, and Cuyuna ranges in Minnesota.

The ore bodies were developed for top slicing in Michigan by driving drifts and crosscuts through them at level intervals of about 100 feet and putting up raises to the top of the ore body or to the level above. Mining started at the top and worked progressively downward; the ore was then mined out by a series of parallel timbered drifts or slices, one alongside the other. When one or more of these slice drifts had been excavated, the number depending on the weight on the timber, the posts were blasted and the back was allowed to come down. Lagging[23] was placed on the floor of the slice to prevent contamination of the ore below. At the top of the ore body, one or two slice levels were often filled with waste wood or lagging to form a cushion for mining

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[22]The earliest reference to top slicing in Lake Superior mining is that in an official Michigan report, which thus described the method at the Cleveland hematite mine:

"The system pursued is peculiar, and is well adapted to ground of this character. The ore is a very soft hematite; the walls have very little sustaining power. . . . . they hold up the ground just long enough to remove the ore and then allow it all to cave in from the surface. . . . . In stoping, they work downwards, taking off about 8 ft. of ore at a time. They drift through to the limit of the ore from the shaft and then work backward, taking the ore 8 ft. high, to the filling, and tramming it towards the shaft to the winze [raise], through which it is run down into the car below and drawn to the shaft. . . . . The effectiveness of this method is shown in the fact that 53,671 tons have been mined the past season, and hoisted in this single shaft in one bucket, which is certainly pretty good work. The force worked at the mine averages about 100 men." Charles D. Lawton, Commissioner of Mineral Statistics, "The Iron Industry," *State of Michigan, Mineral Resources, 1885* (Lansing, Mich.: Thorp & Godfrey, 1886), pp. 33-4.

[23]Lagging is the name applied to small pieces of round or split timber, usually 3 to 6 inches in diameter and 8 feet long.



FIGURE 36.- PUTTING UP A TIMBER SET IN A SOFT IRON-ORE MINE IN MICHIGAN

The men in the picture are timbering preparatory to drilling holes in the breast to advance the cut. The platform was used to set a heavy capping timber on top of the farthest posts. The timber cap was first rested on the two crosspieces nailed to the posts on either side. The men then stood on the platform and raised the heavy timber, one end at a time. After each post has been solidly wedged against the ore walls, the pieces of wood in the platform, called "lagging", will be set above the big timbers in the roof and between the side posts and ore walls to prevent loose ore from caving into the working place. A timber set can be put up by two men in about 35 minutes; to put up a timber set, drill thirteen 7-foot holes in the breast, blast them, and remove the ore with the use of a power scraper requires about 4 hours. The cut is thus advanced about 12 feet in an 8-hour shift.

It is estimated that about one-fourth of the mining time at this mine was devoted to timbering, including the timbering of various passageways which must be kept open. Much of this work consists of replacing decayed timbers or those broken by gradual pressure and ground subsidence. The timber in the working places is not recovered, but, as each level is mined out, the decayed and broken timber serves to form a mat or a "gob" for the level below. This facilitates the caving process and prevents the mixture of ore with waste materials.

Fresh air is constantly blown in through the canvas ventilating tube, shown on the right, to maintain comfortable working conditions. As the cut is advanced, sections of tubing are added so as to bring the air supply to the working face.

below; but after several slice levels had been mined, a mat of timber and rock formed, which was sufficient protection for the miners. The method is classified as a caving system because the overlying rock was permitted to cave and no attempt was made to support the surface.

Top slicing had many advantages over square-set stoping in the mining of Lake Superior soft ores. There were no stopes to be filled; no pillars were left; and the whole ore body was mined by one method. Timber of smaller diameter could be used; this was not only cheaper but more

easily handled. The mining method was safer, for there was little danger from stopes caving and the miners had surer footing, working on solid ground instead of on timber. More development was necessary because raises had to be put up, and before the advent of scraper loading the ore all had to be shoveled, whereas in square-set stoping all the ore above the second floor of the stope was loaded by gravity; but the labor saved in timbering and in filling stopes more than counterbalanced the disadvantages and made possible a larger output per man. The introduction of scrapers and other improvements has further increased the labor-saving advantages of top slicing.

The height and width of slicing drifts have been extended. The early drifts were small, the depth of slice being about 8 feet and the width 7 to 8 feet. At present, a 10-foot post and 10-foot cap are common, so that the height of each slice is 12 feet and the width about the same. On the Mesabi range, where the ore is flat-lying, of great lateral dimensions but limited in vertical depth, 15 feet is a usual height of a slice if more than one is necessary to remove the ore; when one slice is sufficient, it is carried as high as 18 feet. The larger drift permits economy of labor in blasting, loading, and timbering. Since the work is on a larger scale, there is less frequent change of job.

Up to a very few years ago, poor ventilation was a serious hindrance to mining by top slicing in the deeper mines. The slow decay of the timber mat vitiated the air and produced heat. The open areas in the stopes were small, and the ladderways of the raises furnished inadequate passageways for air. In recent years ventilation has been much improved. Not only have powerful fans been installed to increase the air flow through the mine, but the air has been brought directly into the slices by means of tubing. At one of the top-slicing mines where the heat and bad air were formerly excessive, each individual stope is provided with a fan and tube connected directly with the incoming air flow. The temperature in the stopes has been reduced 25 degrees; as a result of this and other changes the production per man-hour has more than doubled.

Sublevel Caving.- Sublevel caving was a natural development from top slicing. It differs from the latter in that some ore is left on each side and above and below each drift slice. This ore is withdrawn on retreat after the drift has been driven to the ore boundary or the property line. Whereas in top slicing the ore itself is not caved but the ground above it is, in sublevel caving the ore left between slicing levels and between the slice drifts is also caved. Although the removal

of this ore usually necessitates some drilling and blasting, the ore, in part at least, is crushed by its own weight and the weight of the overlying mat. Less timber is used, and hence less labor for framing, transporting, and putting up timber is required per ton of ore produced.

Top slicing and sublevel caving are used on similar ores and under nearly similar conditions. Top slicing, however, is practicable only where the material above the slice does not have a tendency to delay temporarily before caving - a condition that is essential for successful sublevel caving. Each of the methods has its advantages. In top slicing, all the space occupied by the ore is opened up and timbered. Extraction approaches 100 percent with practically no dilution. Since in sublevel caving from 50 to 90 percent of the ore is mined without timber, not only supply costs but labor for timbering and drilling is less. Under like conditions, then, the cost of sublevel caving is less, but some ore is lost in the mat and there is some dilution. In some cases top slicing may be used where sublevel caving is not applicable - that is, on the thin, flat deposits of the Mesabi range and on narrow, steeply dipping ore bodies with weak walls where the ore could not be caved without serious contamination. The advantages of block-caving and sublevel stoping over top slicing and sublevel caving have been decreased by the development of scraper loading and by improved ventilation.

The origin of the sublevel-caving method is somewhat obscure. It seems to have been developed independently about 1890 at the Queen group of mines on the Marquette range, the Brotherton mine on the Gogebic range, and the Chandler mine on the Vermilion range. The method is now used in most of the mines of the Gogebic range[24] and to a lesser extent on the Menominee, Mesabi, and Vermilion ranges.

Improvements in the sublevel-caving system have augmented its inherent advantages. In the early use of this method, slices were driven at about 16-foot intervals vertically, the lower 8 feet being removed in the drift and a back of 8 feet left to be caved. Later practice has increased this interval until at present 20 to 25 feet is the usual vertical interval between slice floors, and in some mines the distance is even larger. (The horizontal distance between slicing drifts is usually 18 to 22 feet.) This change has further reduced the amount of timbering necessary and has increased the amount of ore broken by gravity. The

[24]The Montreal mine on the Wisconsin portion of the Gogebic range has recently introduced a modification of the sublevel-caving method, which is called the "sublevel caving, large-pillar" method. The vertical interval between sublevels was increased to 50 feet, and a horizontal, untimbered manway was introduced between the sublevels to help mine out the ore between them. See R. A. Bowen, "Sublevel Caving, Large-pillar Method, at the Montreal Mine," *Mining Technology*, Vol. 2, No. 2 (Mar. 1938), A.I.M.E. Tech. Pub. No. 886, pp. 1-8.

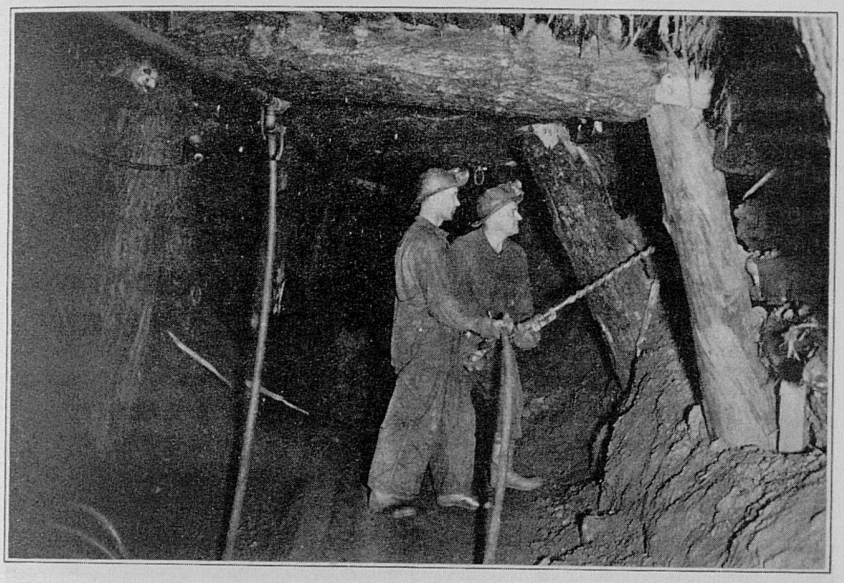


FIGURE 37.- MINING SOFT IRON ORE IN MICHIGAN

The method used at this mine is known as sublevel caving. Mining is begun by advancing horizontal cuts into the ore body at suitable intervals. After each cut has been driven a convenient distance, the miners retreat toward the beginning of the cut, loosening and withdrawing a few feet of ore from beyond the sides and from above the cut.

In the picture the men have chopped a hole through the "lagging", wood pieces at the side, and are drilling holes with a compressed-air auger preparatory to blasting the ore down. The loosened material will then be scraped out with the use of 5-foot scrapers operated by 25-horsepower scraper hoists or "tuggers." Two men can advance a cut about 12 feet in an 8-hour shift. When advancing a cut, two men using auger drills can drill about thirteen 7-foot holes in the "breast" in 1 hour. In drilling holes pointing upward two men handle the drill, which weighs about 50 pounds. For horizontal holes or those inclined downward, each man handles a drill.

dimensions of the slicing drift were also enlarged, affording other labor economies. An 8-foot post and an 8-foot cap are common, though in some cases longer timbers are used.

With the development of scraper loading since the war period, the lay-out of raises and slices in both top-slicing and sublevel-caving systems has been modified to permit more direct ore scraping to the raises. Prior to this, the old, angular lay-out was satisfactory because the cars in which the ore was trammed to the raises were small enough to go around corners easily. With the scraper, however, a straight-line pull was desired. Branch raises have been introduced to provide openings in line with the direct pull of the scraper, and in top slicing a method of radial slicing has been developed.

An important improvement to expedite the work of miners in top-slicing and sublevel-caving mines was the introduction of the ore-storage method about 1927.[25] Formerly miners were often delayed when the raises into

Footnote 25 appears on following page.

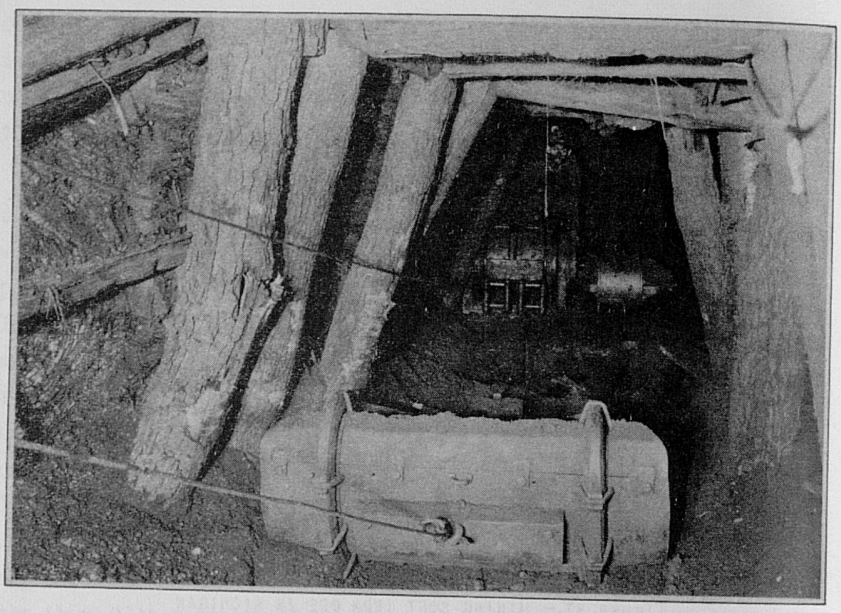


FIGURE 38.- SCRAPING SOFT IRON ORE TO A CHUTE

The adoption of power scrapers was the most important technological development in raising output per man at underground iron mines in the post-war period. The hoe type shown here is 5 feet wide and is scraping ore toward a "grizzly" consisting of steel rails laid across the top of a "raise" or a chute leading to a lower level from which the ore may be loaded into ore cars or transferred to more convenient chutes by means of another scraper. The double-drum hoist or "tugger" operated by the man in the background is equipped with a 25-horsepower electric motor and can pull the loaded scraper at the rate of 300 feet per minute. One drum of the hoist serves to pull the loaded scraper; the other pulls back the empty scraper. The earliest scrapers were pulled back by hand. Before the introduction of scrapers at this mine, the ore was loaded into buggy-type cars with hand tools, and the cars were pushed or "trammed" to chutes by manpower.

which they were dumping ore were filled. This condition was accentuated when scrapers came into use, and the ore was therefore moved from cut to raise more rapidly. This delay has been overcome by providing a place for the storage of ore between the raise and the haulage level. This was done by taking out a drift somewhere below the slice being mined out. The ore could then be scraped to the raise leading to this drift and either stored there or scraped into mine cars. In addition to saving the time of the miner, this method has resulted in a marked reduction in the number of trammers at mines producing a wet or sticky ore. This change alone is said to have enabled one mine in Michigan to increase its output per man by at least 100 percent.[26]

Block-Caving.- A few iron mines have used a mining system called block-caving. In this method blocks of ore as large as 250 feet square and

[25] Roland D. Parks, "Recent Developments in Methods of Mining in the Michigan Iron Mines," *Proceedings of the Lake Superior Mining Institute*, Vol. XXVI (1928), pp. 126-34.

[26] *Ibid.*, p. 149.

from 100 to 125 feet high are entirely or partly cut off from adjoining blocks along the sides by narrow open stopes or shrinkage stopes. The blocks are then undercut with drifts and crosscuts, and the remaining pillars are weakened by drilling and blasting. The blocks are then allowed to settle for as long as a year, during which they are sufficiently broken up by their own weight to be shoveled into cars or drawn off through chutes at the bottom.

Although block-caving requires a higher initial development cost than other methods, once the blocks have been developed and the ore is being drawn, it permits a higher output per man than any underground mining method yet developed. Natural forces are utilized to the fullest extent to break and transport the ore. Production, moreover, is concentrated in small areas permitting more economical utilization of transportation facilities.

The first use of block-caving as a major method in iron mining was at the Pewabic mine on the Menominee range about 1895.[27] There was at that time a market for lean siliceous ore used for mixing with the Mesabi ores. The Pewabic mine was a producer of high-grade ores but also had a large tonnage of siliceous ore that could not be profitably extracted by the usual methods. The next development of block-caving with modifications was at the Tobin mine, also on the Menominee range.[28] The Sunrise iron mine in Wyoming[29] has used block-caving for the past 9 years. The method is no longer in use, however, in the Lake Superior District. Most of the high-grade ore bodies are unsuited for this method, and its future use in mining these ores in the Lake Superior District seems unlikely. In the more distant future, however, it may be used on the siliceous and other low-grade ores when the surface supply is exhausted.

Other Stoping Methods.- The sublevel-stoping system, previously described among the methods employed in the Northeastern States,[30] has been successfully used in the Lake Superior District, especially in the iron mines of the Upper Menominee range in Iron County, Michigan. It is also used to a lesser extent on other Lake Superior ranges.

The sublevel-stoping method is particularly well adapted to natural conditions in Iron County, where the ore varies from relatively soft

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[27] E. F. Brown, "A System of Mining Ore Bodies of Uniform Grade," *Proceedings of the Lake Superior Mining Institute*, Vol. V (1898), pp. 40-5.

[28] Fred C. Roberts, "Block Caving and Sub Stope System at the Tobin Mine, Crystal Falls, Mich.," *Proceedings of the Lake Superior Mining Institute*, Vol. XVI (1911), pp. 218-26.

[29] Information obtained from George H. Rupp, Manager of Mining Department, Colorado Fuel and Iron Corporation, Pueblo, Colo.

[30] See pp. 123-4.

to hard, though most of it may be called medium hard. It is sufficiently self-supporting for open stoping but is not cohesive enough to furnish a safe back. Small chunks become loosened from the back and make working in the open stope hazardous. In the early days both underhand and overhand stoping were tried and found to be too dangerous.[31] Block-caving was used at the Tobin mine, as previously observed, but most of the ore bodies were either too small, too irregular, or otherwise unsuited for this method. With the sublevel-stoping system, miners are always working under a back which can be easily reached for trimming down, and they have an easy, safe exit from the stope. Moreover, with the use of scrapers, sublevel stoping can now be used in flat-lying deposits, and the ore from the stope can be scraped to raises, thus avoiding the rock development that would otherwise be necessary for the removal of the broken ore. Sublevel stoping is applicable in many cases to the same type of ore bodies as is shrinkage stoping; and where the ore is of sufficient width to warrant the additional development (raises and drifts through the ore body), it offers many advantages. It may also be used in ore bodies that dip at too low an angle for shrinkage stoping.

Shrinkage stoping and the cut-and-fill method are among the remaining miscellaneous stoping systems now employed in the Lake Superior District. Both methods are relatively unimportant in tonnage produced. Only one mine now uses shrinkage stoping as a primary method; in all others it is resorted to only for mining narrow ore seams and isolated deposits. The cut-and-fill method was used in mining pillars left between the old square-set stopes at the Chapin mine in Michigan and is now used at the Soudan mine on the Vermilion range.[32] This method resembles shrinkage stoping in that the ore is mined out in horizontal slices beginning at the bottom and working upward. The broken ore is not left in the stopes, however, but is withdrawn immediately. The vacant space is then partly filled with waste rock drawn from an upper level after timber structures have been erected for horizontal and vertical passageways. In the cut-and-fill method the waste-material filling serves the same purpose as the broken ore in shrinkage stoping. It provides a floor for miners to stand on in attacking the next higher slice, and it provides support for the walls. Of course, additional labor is needed to fill the excavated workings with waste material and to cover it with boards to prevent contamination of newly mined ore.

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[31] Roberts, *op. cit.*, p. 218.

[32] See "The Soudan Mine - Oldest in Minnesota," *U. S. Steel News*, Vol. 2, No. 6 (June 1937), pp. 19-20.

Summary

It appears, in summary, that underground iron-mining methods have been greatly improved in the past half-century. Some mines have changed their fundamental mining systems, and all have improved their methods in many details. The change is revealed most strikingly by viewing the underground mines as a whole. The mine constituency of the industry has changed greatly; new mines with more productive mining methods have been opened in new localities and many older, less efficient mines have been abandoned.

Thus in 1880 the bulk of the underground production came from the Northeastern States of the United States where the predominant mining method was open stoping with timber supports in relatively hard ore bodies. In contrast to this, the greater part of the underground output is now produced by caving methods in relatively soft ore bodies. In the 9-year period 1929-37, for which comparable data on mining methods were reported to the United States Bureau of Mines, at least 52 percent of the total output of merchantable ore from underground iron mines was produced either by top-slicing or by sublevel-caving methods; and virtually all of this ore was produced in the Lake Superior District at the average rate of 0.695 gross ton per man-hour. About half of the output by caving methods in the Lake Superior District was produced by mines in Michigan and Wisconsin, and half by mines in Minnesota. The average man-hour output in Minnesota (0.808 gross ton) was considerably higher than in Michigan and Wisconsin (0.607 gross ton). About 36 percent of the total underground output was produced by open-stope methods, principally in naturally supported stopes in Alabama. The average output per man-hour at all open-stope mines was 0.513 gross ton. (See table 16.)

The changes in stoping methods at underground iron mines in the past half-century, reviewed above, have raised output per man in many ways. Through the growing application of caving methods the natural force of gravity has been more fully utilized to break and transport ore, thereby reducing the labor needed for drilling and blasting and for hand shoveling. The abandonment of the stulled-stope and square-set methods and the adoption of such systems as sublevel caving and sublevel stoping have not only greatly reduced the labor needed for timbering and for providing other artificial supports but, together with other improvements, have also diminished the number of accidents. The safest methods have proved more efficient in the long run, for when the workman is free from fear of accident he is more relaxed and accomplishes his task with less exhaustion.

Table 16.- OUTPUT PER MAN-HOUR AND PERCENTAGE OF TOTAL PRODUCTION, BY MAJOR UNDERGROUND IRON-MINING METHOD AND BY AREA, 1929-37[a]

Area	Total[b]	Open-stope methods			Caving methods			Combination open-stoping and caving	Method of mining unreported
		Total	In stopes with natural supports[c]	In stopes artificially supported (shrinkage stoping)	Total	Top slicing	Sublevel caving		
	Output of merchantable ore per man-hour (gross tons)								
United States total	0.606	0.513	0.522	0.431	0.695[d]	0.729	0.621	0.680	0.643
Michigan and Wisconsin	.625	.671	.672	.659[e]	.607[d]	.630	.573	.685	.603
Minnesota, total	.745	.398	.398[f]	(g)	.808[d]	.800	.865	.377	.858
Mesabi and Cuyuna ranges	.829	.719	.719	-	.872[d]	.866	.868	.377	.858
Vermilion range	.551	.256	(g)	(g)	.640[d]	.618	(h)	-	-
Alabama	.546	.550	.550	-	-	-	-	-	.447
New York, New Jersey, and Pennsylvania	.320	.320	.281	.383[i]	-	-	-	.541	.285
All other States	.570	.410	.409	.416	.828[j]	-	.828[j]	-	.275
	Percent of total merchantable ore produced from underground mines								
United States total	100.0	35.9	32.9	3.0	52.4[d]	34.3	16.0	9.4	2.3
Michigan and Wisconsin	45.1	8.7	7.9	0.8[e]	25.8[d]	12.3	12.3	9.3	1.3
Minnesota, total	28.2	1.5	1.5[f]	(g)	25.7[d]	22.0	2.8	0.1	0.9
Mesabi and Cuyuna ranges	21.9	0.8	0.8	-	20.1[d]	17.4	2.1	0.1	0.9
Vermilion range	6.3	0.7	(g)	(g)	5.6[d]	4.6	(h)	-	-
Alabama	20.4	20.4	20.4	-	-	-	-	-	(k)
New York, New Jersey, and Pennsylvania	4.8	4.8	2.6	2.2[i]	-	-	-	(k)	(k)
All other States	1.5	0.5	0.5	(k)	0.9[j]	-	0.9[j]	-	0.1

[a] Data from reports of iron-mining companies to the U. S. Bureau of Mines. (See also table A-22.)

[b] Output per man-hour in this column represents the ratio of merchantable ore produced to all man-hours worked at underground mines. The latter included man-hours at idle mines, or those having development, maintenance, or repair work but no production. These man-hours, amounting to 1.4 percent of the total for the United States, were excluded in computing the output per man for separate mining methods.

[c] Includes room-and-pillar and sublevel stoping.

[d] Also includes mines that reported using a combination of top-slicing and sublevel-caving methods.

[e] Includes one small operation that reported using the cut-and-fill method in Michigan in 1929.

[f] Also includes the cut-and-fill method at one mine.

[g] One mine using this method was included in the total for open-stope methods to avoid disclosure.

[h] One mine using this method was included in the total for caving methods to avoid disclosure.

[i] Includes one operation that reported using the cut-and-fill method throughout the 9-year period.

[j] Includes one operation that reported using the block-caving method throughout the 9-year period.

[k] Less than 0.1 percent.

Concurrently with the progress in stoping methods there have been improvements that have reduced the amount of maintenance and development work. The more frequent mining of ore bodies on retreat to shafts rather than while advancing from the shafts has avoided the need for maintaining and keeping up passageways in areas already mined out. Speedier, larger, and more efficiently designed haulage and hoisting equipment has permitted fewer haulageways and shafts. Vertical shafts have been replacing inclined shafts, with a marked reduction in upkeep cost. Steel and concrete have replaced timber support for shafts and for the more permanent underground openings, such as shaft plats and pump stations.

Gunite, a cement and sand mixture applied with a cement gun, has been used to prevent slacking and slabbing in rock openings where timber support would otherwise be necessary. The driving of drifts, as well as the sinking of larger shafts, is more efficiently accomplished with the use of scrapers with slides for loading ore and rock. These and many other similar developments have contributed to the increase in man-hour output.

Finally, output per man at underground mines has been increased by better planning and mine supervision. Earlier mining depended primarily on the individual miner, who learned the details of his job from his fellow workmen and did much of the planning himself. Today educated and experienced men study and lay out every detail of operation to reduce the amount of wasted time and effort. Work is done according to plan, and a record is kept of the results. The principles of scientific management advanced by Frederick W. Taylor have become better understood and are being applied to a greater extent in mine management. The miner's task is clearly defined and carefully circumscribed, and he is given both the opportunity and incentive to accomplish his daily task. Practically all underground mining in the Lake Superior District is done on the contract or task-and-bonus system. Under this arrangement, if the worker exceeds the work planned for him, he reaps a reward in higher pay.

PROGRESS OF MECHANIZATION AT UNDERGROUND MINES

The rise in output per worker at underground mines in the past half-century is primarily the effect of increased mechanization and successive improvement of drilling, loading, hoisting, tramming, and other equipment. Although the progress of mechanization is closely related to the changes in general mining methods previously considered, its importance warrants at least a brief review here.

Drilling Techniques[33]

The work of drilling and blasting is one of the most important tasks in underground mining. Even now this work requires more than a third of all the employees.[34] Labor requirements for drilling and blasting have been reduced partly by the increase in the proportionate production of soft ore by caving methods and partly by the replacement of

[33] For a full discussion of advances in drilling techniques in iron and other mining industries see C. E. Nighman and O. E. Kiessling, *Mineral Technology and Output per Man Studies: Rock Drilling* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-11, Feb. 1940).

[34] In 1931 the workmen who devoted most of their time to drilling and blasting and closely related activities constituted about 37 percent of all employees at a sample of underground iron mines. (See table A-16.)

hand drilling by power drills and gradual improvements in the latter. In hard-ore mines, power drills replaced hand methods as early as the 1880's. In soft-ore mines, the power auger displaced the hand jumper drill and the hand auger at about the time of the World War.

Since the adoption of power drilling, the piston-type drill has given way to a variety of more efficient hammer-type drills developed and greatly improved for many uses. Drifters, stopers, pluggers, jackhammers, and jackhammer augers are now widely used, each type according to its suitability for drilling in hard or soft materials, for boring horizontal holes, up holes, or down holes, and for heavy or light work. Their use has not only greatly facilitated the work of drilling but has speeded up the whole mining operation, for drilling is a key activity in mining. The recent use of detachable bits, still in the process of development, has increased drilling speed and has decreased the labor required for transporting drill steels to working places.[35]

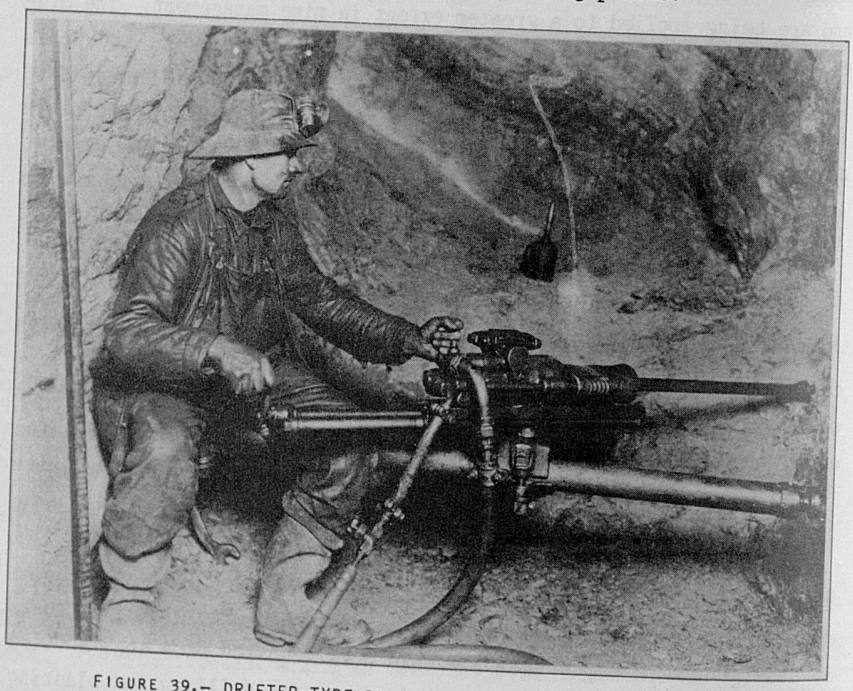


FIGURE 39.- DRIFTER-TYPE DRILL IN A NORTHERN MICHIGAN MINE

Drilling and blasting is one of the most important tasks in underground mining, especially in hard-rock mines. The adoption and improvement of power drills have been important factors in raising output per man. The drifter type shown in the picture is an automatically rotating, mounted hammer drill using hollow drill steel. A mixture of air and water is forced to the bottom of the drill hole to eject cuttings; the water also settles the dust. This type of drill is widely used for drilling approximately horizontal holes in hard material.

[35] Improvements in explosives have been similar to those already described in connection with open-pit mining.

Progress of Underground Transportation*

In the last 50 years underground transportation, both hoisting and haulage, has undergone many changes which have greatly influenced output per man. Almost without exception the trend has been toward larger transportation units, greater and more efficient use of mechanical power, and less manual labor. The changes have been intended more often to increase output without increasing the number of men employed rather than to reduce the number of men required for an unchanged output. The growth in the size of skips and cars has permitted an increase in the size of chute openings and ore passes, as well as improvements in the design of chute closers. These, in turn, have made possible the passage of larger pieces of ore, thereby reducing the amount of sledging and secondary blasting in the hard-ore stopes.

Hoisting Improvements.- It was not until near the end of the last century that a satisfactory self-dumping skip was designed for use in vertical shafts. First used at the diamond mines at Kimberley in South Africa, skips of this kind are now known as Kimberley skips. Until Kimberley skips were introduced at about the turn of the century, there were comparatively few vertical shafts on the Lake Superior iron ranges. Most of the old shafts were inclined, so that self-dumping skips could be used. The few vertical shafts either hoisted ore in cars on cages or used skips of the same design as those used in the inclined shafts, the skip road usually being inclined above the collar of the shaft. These were clumsy, makeshift affairs at best. They were used principally because they made possible the use of an auxiliary service cage in another compartment of the vertical shaft for handling men and supplies. In most of the inclined shafts, men and supplies were hoisted and lowered in the skips, an unsafe and awkward arrangement. The capacity of vertical shafts is generally greater than that of inclined shafts; their maintenance costs are lower; and they are less liable to delays because of accidents.

Since 1905 there have been few, if any, inclined shafts sunk on the iron ranges. The standard shaft is now vertical, has two Kimberley skips in balance, and either two cages in balance or a cage in balance with a counterweight. There have been a few shafts in which a skip and a cage have been hoisted in balance or in which cages have been placed under or over the skips. Either arrangement is unsatisfactory because the skips must be idle when the cages are in use, and vice versa. At

*By Lucien Eaton, Consulting Mining Engineer, Copper Range Company, Painesdale, Mich.

one of the last mines to use cages for hoisting ore, the cages were replaced by skips in 1911, although the hoisting equipment at this mine had been modernized only 13 years before. Capacity was nearly doubled by the change, and the number of men required at the shafts was reduced more than half.

Up to 40 years ago it was the custom to have several operating shafts at one mine and to control and supply power for all the hoisting, if possible, from one engine house. Hoisting engines were built with two, four, or even six drums, each drum having its own operator. The drums were loose on the shafts and were operated by friction clutches, and the shafts were geared to one engine, often with a single cylinder and a flywheel. One skip or cage was hoisted by each drum, and there was usually only one hoisting compartment in each shaft.

Hoisting in balance came next, two skips being handled by one man, and some excellent steam hoists, both direct-connected and geared, were built. The change occurred gradually and few, if any, installations of unbalanced skips were made after 1900. Many of the older plants, however, were kept in service for several years longer. Hoisting two skips in balance in one shaft nearly doubled the hoisting capacity of the shaft with little, if any, increase in labor required. This, together with other improvements in hoisting and loading equipment, reduced the number of shafts until it is now customary for a mine to have only one operating shaft, a second shaft being provided for ventilation and outlet only. This practice started about 1900 and by 1912 was generally accepted, except at very large mines.

Between 1910 and 1920, and following soon after the introduction of Kimberley skips and the change to vertical shafts, electricity replaced steam for hoisting, thus eliminating boiler firemen and coal handlers and increasing hoisting efficiency. The change has been so nearly complete that there is now hardly a mine on all the iron ranges where steam is used for power.

Hoisting capacity has been increased by the use of larger and better-designed skips. Most of the early skips prior to 1900 were small, a common size holding 2 tons. Some of the early Kimberley skips held only 3 tons, but the size has gradually increased until now skips of 5-ton capacity are common and some hold as much as 8 tons. Even larger skips are being considered. The design of the skips has also been improved to reduce dead weight. In the last 6 years the weight of skips has also been reduced, and their capacity has been increased through the use of aluminum and steel alloys and the substitution of welding

for riveting. This has meant greater hoisting capacity and fewer delays with the same plant and the same labor force, resulting in increased output per man.

Along with the adoption of larger skips, underground loading facilities were also improved until now skips are often filled in 3 to 5 seconds, whereas the time formerly required was seldom less than 15 seconds and sometimes a minute or more. At first, end-dump cars were dumped directly into the skips. Then short chutes were used, making practicable the dumping of cars at the sides or through the bottom. Soon the short chutes gave way to pockets holding one skipload, and these are still standard at mines where several grades of ore must be kept separated. The next development was the introduction of large storage pockets, sometimes serving, through chutes, two or three levels, and eliminating loading crews previously required. The ore from the storage pockets is drawn off into small measuring pockets, each of which holds a skipload. The filling of the measuring pockets is controlled by the operator, and the amount of ore put in them is left to his judgment. Automatic measuring pockets, in which exactly one skipload is cut off in the chute by a rising gate, and automatic hoists with push-button control have not been introduced as yet. They are used at some lead and copper mines, and one small iron mine in Wisconsin had an automatic hoist. A change to this type of pocket in the future seems probable.

The size of the service cages has also been increased until they can carry trucks with mine timber or drill steel, locomotives, and ore cars, 10 or more feet long. The cages are entirely enclosed, and their capacity is so large that little time is lost in hoisting and lowering men and supplies. This has reduced the size of the service crews.

In the Eastern magnetite mines, concentration of hoisting capacity, with few exceptions, has not gone so far as on the Lake Superior iron ranges. The majority of the shafts are inclined, and sometimes the ore is "shambled" - that is, hoisted part way in one shaft and then transferred to another shaft - one or two fairly flat underground inclines serving one steeper, main shaft. This requires more hoisting and tramming crews as well as more equipment. The larger mines are equipped with large skips, electric hoists, and underground storage pockets. Changes in hoisting techniques are very marked at some of the mines. At one mine, for example, where today the output is large and all hoisting is done through one shaft, it was the custom 50 or 60 years ago to tram the ore to the shafts in wheelbarrows and to dump it onto a platform from which it was shoveled into a small skip. This practice may well be the origin of the term "plat" to designate a shaft station.

Hoisting methods in the Birmingham District of Alabama, after the outcrop ores were exhausted, followed coal-mining practice very closely. The mines were opened by several slopes driven in the ore, and ore was hoisted in trains of six or more cars, usually of 2-ton capacity, which were dumped in a rotary tipple. This practice is still followed at some shafts.[36] As the mines were deepened, 10-ton skips were substituted for the trains of cars, and the skips were filled either directly from the cars or from pockets. At first the slopes were single-track. Later they were widened for two tracks and were lowered with respect to the ore bed, so that storage pockets and measuring pockets could be used. Skips are loaded and hoisted very rapidly by electricity. A 10-ton skip that is filled in less than 3 seconds travels at the rate of 40 feet per second and handles close to 200 tons per hour. Capacity has been increased to such an extent that the entire output of a large mine is hoisted through one shaft.[37]

Haulage Improvements.- Forty or fifty years ago most of the ore in underground mines on the Lake Superior iron ranges was trammed by hand. Small 1- and 2-ton end-dump cars were pushed by two or three men. These cars, usually designed at the mine and built in the mine shops, were crude and heavy. The output of many small mines was not sufficient to warrant the installation of mechanical haulage even if it had been available. Mules and horses were used underground at some mines, but their use never became general as it did in coal mines. Rope haulage and chain haulage were also tried and discarded.

Some of the earliest electric locomotives ever used underground were put in service on the Marquette range in the early 1890's, and a few mines on the Menominee range installed some compressed-air locomotives. The latter were in service for a number of years, but they were not widely used and were finally superseded by electric locomotives.

Until about the beginning of the World War nearly all of the electric locomotives were of the trolley type. Since then, storage-battery locomotives have been used in increasing numbers, supplementing and sometimes replacing trolley locomotives. The first trolley locomotives weighed 4 to 6 tons each and had heavy cast-iron frames and relatively small motors. The early motors were subject to mechanical difficulties

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[36]Some of the mines still use the small cars, but at others the capacity of the cars has been increased to 5 tons, and in the subshafts (see ftn. 37) two of these are dumped simultaneously into the skip or a pocket is used.

[37]These main shafts extend to depths of 3,000 to 6,000 feet, measured on the incline, and the ore beyond the end of the main slopes is sometimes hoisted or lowered to the storage pocket by auxiliary slopes, which are equipped with cars or skips. The ore body flattens with depth, and there are faults and rolls and reversals of dip which make rehandling almost mandatory. Only two vertical shafts have been sunk in the Birmingham District, but they are not used for hoisting.

which caused many delays, with consequent reduction of output. The ratio of horsepower to weight was gradually increased, with much of the weight being transferred from the frame to the motors, until in present-day models the ratio is about 12 hp. to 1 ton. The most common size of trolley locomotive weighs $6\frac{1}{2}$ tons and has two $37\frac{1}{2}$-hp. motors. It is one of the most reliable pieces of equipment used about the mine. Larger trolley locomotives are used for main-line haulage in some of the larger mines.



FIGURE 40.– UNDERGROUND HAULAGE WITH AN ELECTRIC TROLLEY LOCOMOTIVE

In the two decades prior to the World War electric-locomotive haulage generally superseded hand tramming and the use of mules and horses at underground iron mines. Electric haulage has made practicable larger cars, higher speeds, and longer hauls, and a wider area can be served by one shaft without increasing the number of men needed – an important advantage at deep mines. Since the beginning of the World War relatively small storage-battery locomotives have been used in increasing numbers, supplementing and sometimes replacing trolley locomotives such as the one pictured above. This development further decreased the number of men required for tramming.

Storage-battery locomotives are generally smaller than trolley locomotives, and their motors are about half as large. Their usual speed is $3\frac{1}{2}$ m. p. h., whereas the trolley locomotives run at 7 m. p. h. Higher speeds for both types are used in a few instances. Although storage-battery locomotives of many sizes are in service, 4-ton and $1\frac{1}{2}$-ton sizes predominate. The 4-ton locomotives are used in hauling to the shaft, where the load and the tramming distance are smaller and the service is less severe than that required of the trolley locomotives. They are also used for switching and making up trains, service that does not require high speed.

The 1½-ton locomotives are used with individual cars, directly replacing men or mules and tremendously increasing output per man. It not only reduced the number of men required for tramming but also increased their efficiency in other activities, for the ride on the locomotive served as a resting period after the arduous labor of shoveling.

Coincident with the adoption of electric haulage there has often been an increase in the distance between levels and a concentration of haulage on fewer levels. Larger cars, higher speeds, and longer hauls have been made practicable, and consequently a larger area can be served by one shaft without an increase in the number of men.

The transition from hand tramming to locomotive haulage and the increase in the size of haulage units necessitated wider-gauge track and heavier rails. The track gauge for hand tramming was usually 18 or 24 inches. The standard track gauge now is 30 inches, and the trend is toward 36 inches. The weight of the rails for hand tramming was 12 to 20 pounds per yard, whereas the tracks are now laid with 40- and 50-pound rails. The wider gauge and heavier rails have increased haulage stability and have reduced delays and loss of output because of derailments.

Larger and better-designed mine cars accompanied electric haulage. The hand-trammed cars were nearly all of the end-dump type, and when they were hauled in a train, they had to be uncoupled to be dumped. This led to the development of bottom-dump and side-dump cars that did not have to be uncoupled. Some of the earlier bottom-dump cars were unsatisfactory for coarse or sticky ore and were soon superseded by gable-bottom cars. These dumped at both sides through swinging doors, hinged at the top, and for many years were almost standard. Their maintenance cost was high, however, and they were not entirely suited for coarse or wet ore. When wet ore was hauled, there was much leakage along the track, requiring extra men for track cleaning.

Rotary-dump cars, introduced about 1912, had no doors and were dumped by being revolved in a cylinder placed over a pocket. Where a large tonnage could be handled on one level, they were very successful. They handled coarse or wet ore equally well. The cost of installation, however, was relatively high.

In the last 10 years rocker-dump cars have come into quite general use, especially for handling wet ores. This type of car has a body of V- or U-shaped cross section which rolls sideways on "rockers" or arc-shaped tracks attached to the ends. (See figure 41.) There are no doors, and leakage along the track is slight; but since the center of

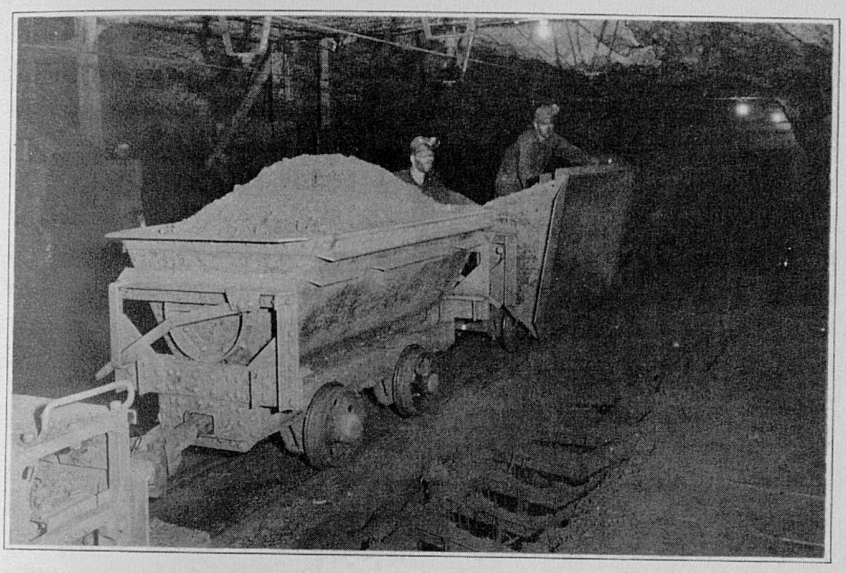


FIGURE 41.- DUMPING ROCKER-TYPE CARS AT AN UNDERGROUND IRON MINE

In the last decade rocker-dump cars with capacities up to about 5 tons have been widely adopted, especially for handling wet ores. Their chief advantage is their small spillage which reduces the labor of cleaning track. The cars are loaded from chutes located on the sides of the haulageways. The chute doors at this mine are opened and closed by a steel gate operated by compressed air - with one man at the controls. Formerly the chute gates were wood planks which were raised and lowered by two men - one at each end. The work was both heavy and dangerous.

gravity is high, its ore-holding capacity is rarely more than 5 tons.[38] Rocker-dump cars have gained favor largely because their small amount of spillage eliminates much of the track-cleaning labor, especially when handling wet ores.

Cars of the Granby type, in which the body is hinged and dumps to one side, the door rising as the box is tilted, have been used in only a few places, although they are quite suitable for the harder ores. In their stead there are a few "drop-door" cars, which also dump to the side, the door turning outward from the top as the body is tilted until, when the full dumping angle has been reached, the door is in the same plane as the bottom of the box. These cars work well with either coarse, fine, wet, or dry ore. They have a low center of gravity and a large capacity but require a relatively wide track gauge. When either type is dumped by a ramp, no labor is required for dumping, and they are often dumped by compressed-air cylinders.

In standard practice all of the mine cars are equipped with automatic couplers, and their wheels have either ball or roller bearings, which

[38] Three-and-one-half- and four-ton cars of this type are most common. Although a recent change in the design of rockers has greatly improved the car's riding characteristics, it limits dumping to one side only.

reduce friction and permit longer trains to be handled by the same size of crew.

In mining by top slicing prior to about 1920 when loading was done by hand, wooden end-dump cars holding 15 to 20 cubic feet were hand trammed on the sublevels. These cars were usually sectionalized so that they could be easily taken through small raises. They were relatively high and narrow and resembled, in design, the 1-ton cars developed in the narrow veins of small western metal mines. Although the design of these cars was later improved, they are now almost obsolete, being replaced by scrapers, which are considered in another section of this chapter.

The early development of underground-tramming equipment in the Eastern magnetite mines followed much the same course as on the Lake Superior iron ranges, but in these mines the ore is coarse, hard, and dry and is not like the fine or sticky ore of the hematite mines. Granby cars of 3- to 7-ton capacity are common and are well suited to mine conditions. They are usually dumped by air cylinders instead of by ramps. Both storage-battery and trolley locomotives weighing as much as 10 or 11 tons are used at the large mines, and hauls are relatively long. Track gauge is commonly 36 inches.

In the Birmingham District of Alabama, transportation equipment has very closely followed coal-mine practice. The early mine cars were wooden, 2-ton-capacity cars with chain couplers. They were either of end-dump design or were dumped in a rotary tipple, and cars of these types are still in use. At other mines the capacity of the cars has been increased to 5 tons, and they are dumped endways by air cylinders or sideways in a rotary tipple. Some of the smaller cars are hauled by mules, but the large cars are hauled by trolley locomotives, some of which weigh as much as 20 tons. Track gauges are generally wider than in northern mines and in some of the newer installations are 4 feet $8\frac{1}{2}$ inches, the standard railroad gauge. As the gauge has been widened, the weight of rail has been increased, 70-pound rail being common. Better tracks, larger cars, and longer trains have increased the output per train crew.

Improvements in Chutes and Chute Closers.- In order to keep pace with improvements in cars and locomotives, chutes and chute closers had to be changed also, for the time required to fill a train of cars was often longer than that required for hauling. The larger cars permitted larger chute openings, and the larger openings made stronger and better gates necessary.

In the early days of the Lake Superior mining, two types of chutes, classified according to the type of closer or gate employed, were in general use. The first was the stopper-board chute, in which the flow of ore was stopped by 2-inch boards placed across the chute mouth and held in place by cleats or angle irons attached to the sides. Sometimes two rows of boards were used, the board farthest from the lip of the chute being higher than the other, and stop logs were sometimes used in place of the upper board. This type of chute is still in general use where the service is not too severe and the chute is to be used only for a short time. Minor changes in design are made to suit local conditions, but the principle remains unchanged. The second type of chute had a hinged metal lip, which was lifted by a bridle attached to a lever or windlass. When the lip was lowered, the ore flowed over it; when it was raised, the flow stopped. These chutes were especially effective in handling coarse ore and are still used occasionally.

For more rapid loading of fine ores, overcutting arc gates operated by hand levers took the place of the stopper boards in many mines. In this chute a curved steel plate is attached by radial arms to a shaft, which rests in bearings on the sides of the chute. It is raised and lowered by a lever attached to one end of the shaft.[39]

For handling coarse ore in the hard-ore mines, as an improvement over stopper boards or hinged lips, Treadwell finger chutes were introduced on the Marquette range about 1910 and are still in use. (See figure 42.) In this chute the ore is held in check by seven wooden fingers faced with steel and hinged at the "knuckle." They move independently on a 2-inch iron shaft placed across the top of the chute opening, and they push down and against the stream of ore. Because they are independent in action, their effectiveness is not impaired by the presence of large chunks. Some fine ore which can get by or between the fingers

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[39] Two styles of such chutes are used; in one the plate, or "arc", is above the shaft in the throat of the chute, and in the other it is below the shaft close to the lip of the chute. The former is probably more popular.

Overcutting arc gates do not work well with coarse ore because chunks catch under the arc and prevent closing, thereby causing delay. To overcome this difficulty, the arcs were made to rise through the stream of ore from below, the chute being called an "undercutting arc gate." The arc is placed below the shaft at the mouth of the chute. It is operated by a lever and, when closed, is held in place by a counterweight. These chutes are not in common use on the Lake Superior iron ranges but are used by a few mines there.

Storage pockets and measuring pockets for filling skips use a variety of gates. The simplest is a straight, overcutting, vertical door, sliding between guides and raised and lowered by an air cylinder. Both overcutting and undercutting arc gates are also used. Probably the fastest loading is done with a hinged door in the bottom of the pocket, which is held in place, when closed, by a toggle. When the toggle is broken, a section of the bottom of the pocket drops down instantly, leaving an unobstructed opening for the passage of the ore. When the pocket is empty, the door is closed by a counterweight. The chutes from the storage pockets are often closed by fingers, which may be of the Treadwell type or may be vertical steel bars, 3 inches square, sliding through iron guides. They are raised by large air cylinders and close by gravity.

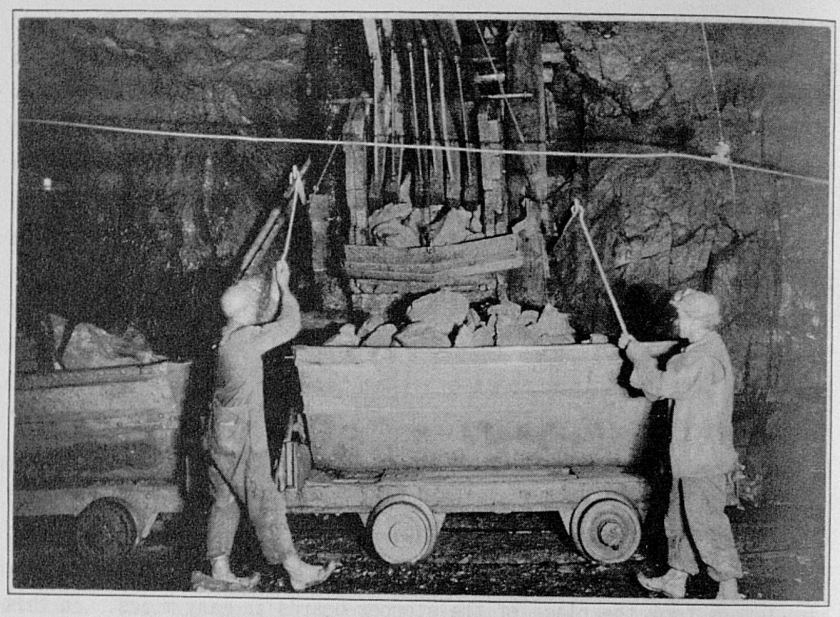


FIGURE 42.- FINGER CHUTE USED FOR HANDLING COARSE ORE IN HARD-ORE MINES

This type of chute gate has proved satisfactory in controlling a stream of ore containing large pieces. The flow of fine ore is controlled by the hinged gate below the fingers. When the ore runs freely in the chute, two men operating the fingers and gate can load at least twice as much ore in a shift as they could by using stopper boards.

is held back by a hinged gate much like an overcutting arc. Both fingers and gate are raised by a rope or chain attached to a lever or an air-lift cylinder. In a freely running chute, two men can load at least twice as much ore per shift with fingers as with stopper boards.

In some mines, when the ore is wet and water collects in the ore passes, it has been found more economical to eliminate the use of chute closers and to allow the ore to run out on the floor of the drift, from which it is loaded into cars over a slide by means of a scraper. The same principle is followed in "transfer" drifts on sublevels where the ore from several chutes is dragged by a large scraper to a main ore pass.

The size of the chute opening has been increased from a width of about 2 feet and a height of $1\frac{1}{2}$ feet to a width of 3 or more feet and a height of 2 to $2\frac{1}{2}$ feet. Through the use of larger chute openings and better gates, it is now possible to load a 5-ton car in less time than was required formerly to fill a 2-ton car.

In the Eastern magnetite mines, stopper-board and hinged-lip chutes have been largely superseded by other types. Some mines use undercutting arc gates which are raised by hand levers or by air cylinders placed beneath the chute. Others use a simple chute closer made of a piece of square or round timber attached at the ends to iron straps, which act as

radial arms and are attached to the sides of the chute. The timber lies across the mouth of the chute and is raised by hand. One mine uses large, vertical, sliding doors operated by large, double-acting air cylinders. In these mines the chute mouths have been widened to $3\frac{1}{2}$, 4, or 5 feet to permit the passage of coarse ore and may be as high as $3\frac{1}{2}$ feet.

In the Birmingham District the dip of the ore is so flat that no ore is loaded into cars by gravity. Cars are filled by large scrapers, or "drags", which drag the ore up a ramp. This type of loading has taken the place of hand shoveling, and output per man has been increased tremendously thereby.

Mechanization of Underground Loading

The greatest technical advance in iron mining in the post-war period was the mechanization of underground loading.[40] Prior to the World War, hand loading or mucking was the most laborious and time-consuming task in underground mining.[41] The introduction, and improvement, of mechanical loading greatly lightened this task and speeded up the whole mining process. It increased the output of the miner in the stopes by from about 20 to as much as 200 percent;[42] at the same time it reduced the amount of maintenance and development work and permitted a more efficient utilization of transportation equipment.

Prior to the introduction of mechanical loaders, hand shoveling was reduced principally by the development of gravity-loading methods of mining.[43] Gravity, however, could be utilized only to a limited extent in mining most of the iron-ore deposits. Even in developing those ore

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[40] For a more detailed discussion of mechanization of underground loading in all metal mines, including iron mines, the reader is referred to the following: Charles E. van Barneveld, *Mechanical Underground Loading in Metal Mines* (Rolla, Mo.: Univ. of Mo., School of Mines and Metallurgy, May 1924); Robert C. Matson, "Scraping Practice in the Michigan Iron Mines of the Lake Superior District," *Proceedings of the Lake Superior Mining Institute*, Vol. XXVI (1928), pp. 196-270; *Handbook of Scraper Mucking* (Chicago, Ill.: Sullivan Machinery Co., Pub. No. 176, 1931); Chas. F. Jackson, *Underground Scraping Practice in Metal Mines* (U. S. Dept. Int., Bur. Mines, Manuscript Report No. 1 [reprinted by Sullivan Machinery Co., 1933]); 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* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-3, June 1937); McHenry Mosier and J. H. Steinmesch, *Mechanical Shoveling in Underground Metal Mines* (U. S. Dept. Int., Bur. Mines, Bull. No. 423, in press); and *Modern Methods for Scraper Mucking and Loading* (1st ed.; New York: Ingersoll-Rand Co., Form No. 2412, 1939).

[41] Time studies indicated that hand mucking required from 35 to 50 percent of the total time of miners per shift. See Ford E. Boyd, "Slushing Practice in the Mines of the Oliver Iron Mining Company," *Proceedings of the Lake Superior Mining Institute*, Vol. XXIII (1923), p. 68.

[42] Unless otherwise stated, these advances represent relative increases in the daily productivity of muckers who also did other work such as drilling, blasting, and timbering.

[43] Some minor improvements had been made also to increase the efficiency of hand shoveling by improving the shape and proportions of shovels; by reducing the height of cars, thus reducing the shoveling lift; by laying wooden or steel shoveling plats prior to blasting instead of shoveling off the rough floor; and by pairing left-handed and right-handed shovelers in narrow working places.

bodies that were best suited for gravity loading, a considerable amount of hand shoveling was unavoidable. Mechanization of loading, therefore, offered the principal means for reducing the large volume of labor required for hand shoveling.

Although experiments with underground mechanical-loading devices began as early as the end of the last century,[44] no serious attention was given to this problem until the World War had created a shortage of labor and had greatly increased wages.[45] Two types of machines were then introduced, shovel loaders and scraper loaders.

The small, underground power shovel first seemed to offer the best prospects for reducing mucking costs, and during the war period a large variety of shovel loaders were developed. Many types were tried in iron mines, and some were successful. Shovel loaders were used to best advantage in driving tunnels or headings and for ore-loading work in large open stopes. Rapid progress was made meanwhile in the development and use of scraper loaders, and many operators found them more practicable. The repair and maintenance cost of the first shovel loaders was relatively high. Moreover, the conditions at most iron mines were not suitable for this type of equipment. Most of the ore bodies were excavated by top-slicing and sublevel-caving methods; the tramming drifts were relatively small, and scraper hoists that took up very little room were found more satisfactory. By 1924 shovel loaders were definitely passing out of favor, and scraping became the predominant method of mucking at most iron mines.[46]

A $2\frac{1}{2}$-hp., air-driven, single-drum hoist, introduced in 1912 for general use about mines as a timber hoist, was soon adapted for dragging ore. A scraper was attached to a rope and dragged toward the hoist, or "tugger", as the drum of the latter rotated and wound the rope on it. As it was a single-drum hoist, the rope pulled in only one direction, and the scraper had to be pulled back by hand.[47] In 1920 a more powerful,

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[44] In 1898 a small air hoist with a slip scraper was used to distribute filling in the square-set stopes of the Badger iron mine on the Menominee range. The hoist was of the kind then used for hoisting timbers. See van Barneveld, *op. cit.*, p. 212.

[45] It was reported, for example (*ibid.*, p. 4), that: "When the shortage of labor, especially of unskilled labor at a time of maximum demand, seriously affected production and it was fully realized that the issue must be faced, the efficacy of mechanical mucking suddenly became a live and pressing question in several important mining districts and an accomplished fact in a surprisingly short time."

[46] The recent development of a small mine-car loader that has proven satisfactory for general use in drifts as small as 6 by 7 feet may presage a wider use of shovel loaders in iron mines, especially for development work on bottom levels where working conditions are unfavorable and it is imperative to increase the speed of advance. Scrapers, used with scraper slides, are at a disadvantage in this kind of work as the amount of material to be handled for each set-up of the scraper rig is relatively small; some hand shoveling is also needed for the final clean-up.

Footnote 47 appears on following page.

4-hp., double-drum hoist was introduced, with the drum faces opposite each other. By 1923 improved types of air-driven, double-drum hoists of 8- and 10-hp. capacity were available, and the drums were arranged end to end and on a common shaft.

Adoption of Scraper Loading.- The greatest growth in the use of power scrapers in iron mining took place from 1920 to 1929, with consequent large increases in output per man. Indeed, many mines had completely changed over from hand shoveling to power scraping in the span of only 3 years, 1920-23. By 1923, for example, the largest iron-mining company in the Lake Superior District was using 82 single-drum slusher hoists and 8 double-drum hoists in its operations on the Mesabi range. These scrapers handled from 62 to 100 percent of the total production of the mines in which they were installed, and the output of the miners using scrapers was from 18 to 35 percent higher than that of hand-shoveling gangs. In its deeper mines on the Vermilion and Gogebic ranges, the same company was using 64 hoists, all double-drum machines, which handled 24 to 65 percent of the total production. The output of miners using these double-drum scraper hoists was 63 to 107 percent higher than that of miners using hand methods.[48]

The rapid mechanization of loading at underground iron mines in the post-war period is also indicated by the number of mechanical loaders sold annually to iron-mining companies. During the 14 years 1923-36, for which data are available, iron-mining companies in the United States purchased a total of 2,824 scraper loaders. (See table 17.) More than three-quarters of the total was purchased in the first 7 of the 14 years. Over the same period, sales of shovel loaders have been very small, totaling only 64.

Scraper loaders have now been introduced in virtually all Lake Superior iron mines where conditions permit their use. Scraping was found to be most advantageous in fairly flat deposits, especially in the soft-ore mines of the Lake Superior District using the top-slicing method, where a large amount of ore can be handled with each set-up of the scraper and where the ore can be scraped into chutes. The development of heavier scrapers and more powerful hoists, however, has also made them useful for dragging hard, rough, chunky ore. Scraper slides,[49] moreover, have

[47] In an iron mine on the Marquette range a single-drum hoist was converted into a double-drum hoist by placing a dividing flange in the middle of the drum and reversing the engine to pull back the empty scraper. In at least one other mine on the Mesabi range a double-drum hoist was developed by bolting together two single-drum hoists.

[48] Boyd, *op. cit.*, p. 77.

[49] Scraper slides in iron mining were first developed in Michigan. A large variety of slides were built in mine shops, and manufacturers have made available portable slides, many mounted on wheels so they could be moved easily from place to [*Con.*]

Table 17.- NUMBER OF SCRAPER LOADERS AND SHOVEL LOADERS SOLD TO IRON MINES IN THE UNITED STATES, 1923-36[a]

Year	Scraper loaders[b]	Shovel loaders
Total	2,824	64
1923	216	17
1924	200	5
1925	290	7
1926	202	6
1927	340	4
1928	287	2
1929	569	15
1930	266	3
1931	81	0
1932	76	0
1933	37	0
1934	44	2
1935	89	3
1936	127	0

[a]Compiled from reports of manufacturers to the U. S. Bureau of Mines.
[b]Includes hoists or complete units.

enabled the loading of cars standing on the same level from which the material is loaded, thus permitting the use of scrapers in hard-ore mines in the Lake Superior District as well as in the Birmingham District and, to a lesser extent, in the Eastern magnetite mines. Scrapers with slides are also effectively used for development work, such as driving tunnels or headings.

Changes in Scraper Loaders.- As already noted, the first scraper loading done at most iron mines was with single-drum hoists. When used with slip scrapers,[50] the method is called slushing. Around 1923, slushing with single-drum air hoists was the predominant method of scraping in the soft-ore, top-slicing mines of the Mesabi range and, to a lesser extent, elsewhere in the Lake Superior District. Two men were required

[49][*Con.*]place by the mine locomotive. The scraper slide "consists of an apron that rests, at its lower end, on the floor of the drift and forms the lower end of a slope. The slope proper continues from the apron to a height that is above the top of the car that is to be loaded. This slide or slope has a solid bottom as the muck has to be hauled up it. After reaching its extreme elevation the slide is turned flat and continues the length of one or more cars, as it may be designed. The flat part is open bottomed and is the discharge end for the scraper load.

"The hoist for moving the scraper is mounted on a plat over the inclined portion of the slide. It is double drum and of sufficient power to move the loaded scraper over a rough bottom and with plenty of overload capacity." See A. C. Stoddard, "Mechanical Mucking Underground vs. Slushing," *Skillings' Mining Review*, Vol. 25, No. 27 (Oct. 31, 1936), p. 1.

[50]The slip scraper or slusher differs from other scrapers in that it picks up and carries the load instead of scraping or dragging it.

to operate the slusher. One worked the hoist, and the other handled the slusher while digging, guided it while it was being hauled in, dumped it into the chute, and pulled it back to get another load. As this was hard work, the men frequently changed places.

Despite the additional labor needed to operate the single-drum hoist, it was preferred over the double-drum hoist for some time even after the latter had become available. Since the single-drum machine was relatively light, weighing about 300 pounds, it could be moved about by the two men who customarily worked together in each slice drift, without the assistance of other gangs. Furthermore, though the double-drum scraper hoist required anchoring the tail sheave, this was unnecessary with the single-drum hoist; no time was lost in rigging up, and a crew could start slushing sooner. Moreover, the single-drum outfit was more flexible; the miner steering the slusher could more easily guide it around timbers and other obstructions. It was soon realized, however, that double-drum hoists were more economical, and this is now the usual type. Additional reasons for the change were summarized by van Barneveld as follows:

> That slushing, though a very decided move in the right direction, was only a partial solution of the loading problem soon became evident. It increased the production and the compensation of miners but did not greatly decrease their physical effort, being particularly hard on lightweight men and not at all satisfactory in lumpy material. The solution evidently lay in eliminating hand manipulation of the scraper during filling and the walk in both directions. This led to experiments which evolved the present bottomless, self-filling, self-dumping scrapers, moving by means of main-and-tail rope haul and operated by double-drum hoists of various degrees of portability.[51]

Until about 1924[52] all scraper hoists were air-driven. Compressed air was available in the mines because of the general use of pneumatic drills. Moreover, the air escaping from air-driven engines made working conditions more comfortable in poorly ventilated places. It soon became evident, however, that the simultaneous operation of a number of drills and scraper hoists required more air than could be supplied conveniently, especially since the more rapid rate of mining increased the amount of drilling. In some instances the air compressor was too small,

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[51] Van Barneveld, *op. cit.*, p. 239.

[52] In April 1924 one manufacturer began to supply portable, 6½-hp. electric hoists after a year's successful operation of a machine at the Montreal mine on the Gogebic range, where it was mounted on a metal scraping slide and loaded cars standing on the same level from which material was scraped. At the Cliffs Shaft mine on the Marquette range an air-driven hoist was successfully converted into an electric one by replacing air cylinders and connecting rods with a 25-hp. electric motor. The hard, lumpy ore at this mine necessitated a heavy, 1,400-pound scraper - hence the unusually large hoist.

but more often the distribution system was inadequate, being designed merely for drilling and timber-handling needs. Although later models of air-driven hoists were improved so that they gave good service even at lower air pressures, electric motors were found more satisfactory, especially for the larger, double-drum hoists. Electric hoists were quieter and speedier in their operation, easier and cheaper to operate, and required much less power per ton scraped.[53] With the trend toward more powerful hoists, electric machines have been generally preferred to air hoists, and many operators have made replacements with electric units.

As scraping came to be done over longer distances, higher rope speeds were required and more powerful hoists were developed. The use of heavy scrapers for development work in rock and for dragging hard, chunky ore also necessitated larger hoists. Mine operators, moreover, discovered that more powerful scrapers were more economical in the long run, even for ordinary scraping in soft-ore drifts. As a result, the trend in the past 15 years has been toward larger scraper hoists.

As previously noted, some of the first single-drum, air-driven hoists had only $2\frac{1}{2}$ hp. Later, 6- or $6\frac{1}{2}$-hp. hoists were preferred for slushing in soft-ore mines. With the gradual abandonment of single-drum hoists and a wider application of scraping, many larger hoists were adopted. By 1928, in all of the mines on the iron ranges in Michigan, for example, there were in use approximately 400 double-drum electric hoists and 150 air hoists.[54] About 350 had a capacity of 6 to 10 hp.; most of these were $6\frac{1}{2}$-hp. double-drum hoists. The remaining 200 hoists were rated from 15 to $27\frac{1}{2}$ hp., mostly either 25 or $27\frac{1}{2}$ hp. Present-day operations are equipped with scraper hoists ranging from 6 to 35 hp., and the recent policy of many operators is to purchase no new hoists that are rated at less than 15 hp.[55]

The increase in size of hoists was accompanied by an increase in rope speeds. Many mines that had formerly used hoists of 5 to $7\frac{1}{2}$ hp. with a pulling rope speed of 150 feet per minute are now equipped with 15-hp. hoists that have rope speeds of 200 to 280 feet per minute.[56]

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[53] A comparison of power costs of air hoists with electric hoists in soft-ore, top-slice mining in Michigan revealed that the per-ton power cost for operating air hoists was about eight times as large as for electric hoists. (See Matson, *op. cit.*, p. 240.)

[54] *Ibid.*, p. 238. The smaller, more compact, 6- to 10-hp. hoists were readily handled through raises and were used for scraping ore in the stopes. The larger hoists of about 25 hp. were used where the amount of hoist shifting was small and where a large amount of heavy work was required for each setting of the hoist, as in a transfer drift.

[55] See Jackson, *op. cit.*, p. 32.

[56] *Ibid.*



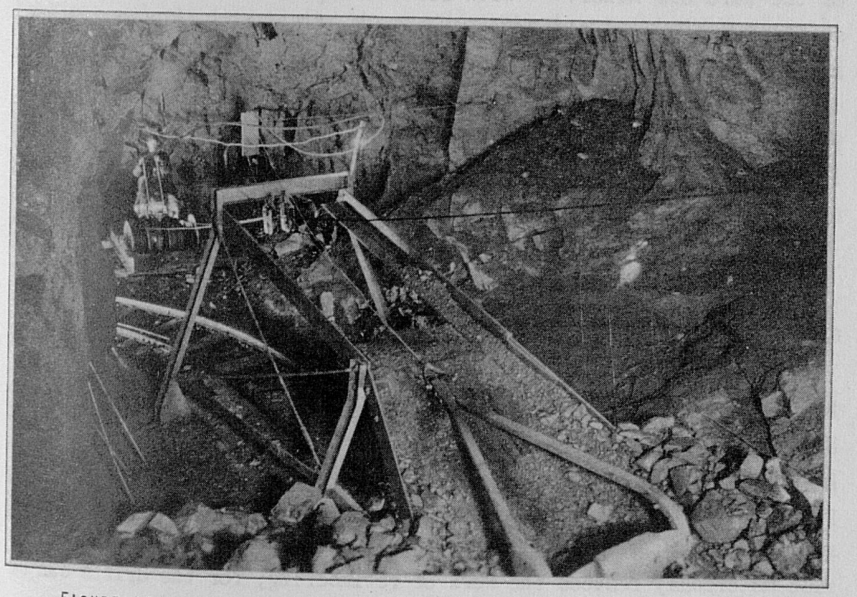


FIGURE 43.- HAND AND MECHANICAL LOADING AT A HARD-ORE IRON MINE

Before the World War hand loading was the most laborious task in underground mining. The mechanization of loading in the post-war period greatly lightened this task and speeded up the whole mining process, with a consequent increase in output per man.

Although scraper loaders were most suitable for handling soft ore, they were also successfully adapted to loading hard, chunky ore. It was found that powerful hoists and heavy scrapers, when used in conjunction with scraper slides such as the one shown in the lower picture, were much superior to hand-loading methods.

Scraper-loading efficiency was greatly increased, not only by improvements in the machines but also by a better selection of equipment for particular loading needs and by a better adaptation of mining methods and lay-out of mine workings to take full advantage of scrapers. Thus in many mines radial slicing has replaced parallel slicing to permit more scraping directly to chutes; raises have been introduced at points more convenient for scraping; and storage or transfer drifts have been developed to facilitate faster removal of ore scraped into raises and thus avoid the loading delays formerly encountered. The latter improvement alone has been credited by one observer with increasing loading efficiency to a larger extent than has the introduction of the scraper itself.[57]

Gains in Output per Man.- From the outset, even before the many improvements in scraper equipment and adaptations of mining methods, the adoption of scraper loading was reflected in advances of about 20 to 100 percent in the output of iron miners in soft-ore mines and in many of the hard-ore mines.[58] With further improvements in scrapers and scraping conditions, the increase over hand-loading rates amounted to as much as 200 percent.[59] The tasks performed by the miners include drilling, blasting, and timbering as well as loading. If the loading performance only is considered, scrapers handled from 3 to 10 or more times the amount per miner-hour that was formerly hand-shoveled into cars, trammed a short distance to chutes, and dumped.[60]

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 transportation 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. More rapid mining with such methods as top slicing and sublevel caving has also materially reduced the work of retimbering, for the drifts can be

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[57] See Parks, *op. cit.*, p. 149.

[58] See p. 153; also van Barneveld, *op. cit.*, pp. 235, 238, 262, 268, 275, 300-2, 310-11, 314; also Jackson, *op. cit.*, p. 66; also W. R. Crane, "Red Iron Ore Mining Methods in the Birmingham District," *Transactions, A.I.M.E.*, Vol. LXXII (1925), pp. 176-7.

It should be noted that a given increase in tons loaded per miner-shift has not necessarily been accompanied by an equal increase in productivity of all employees (including miners and other underground employees and surface employees); equal advances have generally not been made in the efficiency of performance of tasks other than loading.

[59] See *Handbook of Scraper Mucking*, p. 11.

[60] *Ibid.*, pp. 7, 9; see also van Barneveld, *op. cit.*, pp. 216-7, 227.

mined out more easily before ground subsidence has injured the timbers. This development, coupled with the increase in scraper-rope speeds, has sometimes enabled mine operators to make savings by increasing the length of the drift slices and spacing the raises farther apart. In fact, the use of power scraping has enabled many underground mines in the Lake Superior District to compete more successfully with open-pit operations; without the development of mechanical loading underground the shift of production to open-pit mines would have been more rapid than it was.

PROSPECTS FOR TECHNICAL ADVANCES

Future underground-mining methods will depend largely on the nature and location of the ore bodies mined and upon economic conditions. For the next decade at least, ore bodies and operating conditions similar to those of today are probable. As no new basic methods of mining have been devised during the past 30 years and every known mode of attack on ore is being applied, it seems likely that further progress will come from more exactly determining the stoping method or combination of methods most suitable for particular ore bodies and from working out the details with still greater refinement. Further economies in drilling, loading, haulage, and hoisting are also likely, but it is difficult to conceive of any new mechanical improvement that would have so great an effect on labor productivity in underground mines as did the introduction of scraper loading. Technical advances are continuing, however, especially in the adaptation of mining methods to available equipment, and the best practices are being more widely adopted. Although an early spurt in technical progress cannot be foreseen at this time, the aggregate result of many small improvements will probably be significant.

CHAPTER VI

PROGRESS IN THE BENEFICIATION OF IRON ORE*

The influence of advances in ore beneficiation in maintaining output per man despite depletion of high-grade, direct-shipping ore deposits has already been mentioned in chapter III.[1] In this chapter the nature and purpose of ore beneficiation are more closely examined. Moreover, since beneficiation seems destined for an increasingly important role, the factors involved in its continued expansion and progress are given special consideration from the standpoint of the future of the domestic iron-mining industry.

NATURE AND PURPOSE OF ORE BENEFICIATION

The beneficiation of iron ore is the use of any processing method for the purpose of improving the physical structure or the chemical composition of the ore. The physical structure may be improved by breaking coarse lumps into smaller particles or by agglomerating fine particles into coarser lumps. The chemical composition is improved by a process ordinarily called "concentration." In this process the ore is separated into two or more parts, of which one at least is of greater value per ton than the original ore, and the more valuable parts are saved while the others are rejected.

Ore is beneficiated before being smelted in order to reduce the cost of producing pig iron. Beneficiation aids the attainment of this objective by curtailing the cost of transporting iron contained in material shipped from the mines to the blast furnaces and by reducing smelting costs. The cost of transportation is cut by shipping more units of iron per ton of material, since before shipment the ore is concentrated by the removal of that portion containing little or no iron. Smelting costs are radically affected by the rapidity with which the ore smelts, by the amount of fuel required to smelt it, and by the amount of fluxing materials that must be added to the furnace charge. If the ore as mined does not have the desired smelting qualities, its structure and chemical analysis may be modified by the use of beneficiation processes.

For the production of a ton of pig iron, it is usually necessary to charge the blast furnace with about 2 tons of iron ore, 1 ton of coke,

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*By E. W. Davis, Director, University of Minnesota Mines Experiment Station. In addition to serving in a consulting capacity, Mr. Davis prepared a detailed background study of ore beneficiation, and the principal findings of this larger study are summarized in this chapter.

[1] See ch. III, pp. 27-9.

one-fourth of a ton of limestone, and then to blow through this mixture 4 tons of air to obtain combustion of the coke. Not only must the furnace charge contain the correct proportions of ore, flux, and coke, but the physical characteristics and distribution of the charge must be such that the required amount of air can be forced into the mixture at a minimum pressure and in a minimum length of time, with the least loss of fines and maximum recovery of metal. The smelting operation results in the following products: (1) Pig iron, which contains virtually all the iron, all of the phosphorus, and a small percentage of the carbon and silicon in the charge; (2) slag, which contains most of the solid waste materials and most of the sulphur in the charge; and (3) gases, which contain most of the carbon, moisture, and other volatile and gasified constituents of the charge. The pig iron is used for steel making and for foundry purposes. The slag is ordinarily a waste product but is sometimes used in the manufacture of cement or as aggregate for concrete. The gas is combustible and is used for various purposes around the smelting plant. The production of pig iron of specific and predetermined quality is of great importance, as such a product is required in most fabrication. In order to produce cheap pig iron of desired quality, the blast-furnace operator must have raw materials of proper chemical composition and physical structure.

Early blast furnaces were constructed in localities where desired grades of iron ore and other raw materials were readily available; but as the demand for iron and steel increased, plants were enlarged and larger deposits of ore and greater quantities of fuel were sought. As local or nearby ore was no longer available in sufficient quantities and of a quality to meet the demand, in order to utilize the new supplies obtained at a distance it was frequently necessary either to modify the ore or modify the design of the furnace and the methods of smelting. Both types of adjustment were made. The design and operation of blast furnaces were changed especially to make use of Mesabi ores. Most of this ore was of a soft, earthy nature, originally considered unsatisfactory for blast-furnace use. The great magnitude and easy accessibility of the deposits, however, provided the incentives for technical adjustments to permit greater use of these ores. Such satisfactory methods were developed that at the present time 60 percent of the ore used in the United States normally comes from the Mesabi range. It should be noted, however, that although it is possible to change smelting methods and the design of blast furnaces to suit more nearly the general characteristics of available ores, the practical extent of such modifications

is definitely limited. It is more generally necessary to modify the ore to suit the customary furnace and smelting techniques.

PRINCIPAL METHODS

A number of processes, such as crushing, sintering, washing, jigging, and magnetic concentration, are in general use for modifying the ore to suit more nearly the needs of the furnaces. These processes may be used singly or in various combinations, but the name used to describe any particular beneficiating plant is usually the name of the most important of the various processes used in that plant. Crushers, for example, are used in most concentration plants, but the term "crushing plant" is applied to one in which only crushers and screens are used. At such plants the larger pieces of ore are crushed to obtain material more satisfactory for blast-furnace use.

Although the term "beneficiation" applies to all methods for improving the quality of ore, the term "concentration" applies only to those beneficiation processes that materially improve the chemical composition of the ore. Concentration processes will be increasingly important in the future. Since it is expected that the ore requirements of the country will continue to be supplied by domestic mines, iron-ore concentrate will eventually replace the direct-shipping ore now obtained from the rapidly decreasing reserves of high-grade ore unless new high-grade deposits are found.

In the sintering process very fine ore is agglomerated into coarser porous lumps by incipient fusion with heat produced by combustion within the mass itself. Although it is frequently used in combination with other processes, many beneficiation plants use sintering only. In most plants of this type fine material is sintered simply to improve the structure of the ore, but in a few plants the process is employed primarily to raise the iron content of the shipping product. In the latter instance, the heat drives off practically all the moisture and volatile constituents of the iron ore, and sintering is a real concentrating procedure similar to washing, jigging, and magnetic separation.

Washing is the most important concentrating method in use at the present time. It is used extensively in Minnesota and Alabama on certain iron ores in which the coarser particles are mostly iron-bearing material and the finer particles are mostly sand. To produce a desirable furnace product from this ore, it is necessary only to abrade it slightly and to wash the sand away from the larger particles.

Jigging is applied to ores containing particles of rock so coarse in size that they cannot be washed away from the valuable iron material

in the ore. In this process, advantage is taken of differences between the specific gravities of the rock and of the iron-bearing particles; when agitated under proper conditions the lower specific-gravity rock particles collect on the surface of a slowly moving mass of ore from which they can be skimmed off and rejected. Although the jigging process has been used extensively for cleaning coal, its extensive use for concentrating iron ore is a recent development and is confined principally to Minnesota.

Magnetic concentration has been used for many years in New York, New Jersey, and Pennsylvania, and it seems probable that with certain improvements it will be used extensively at some future time in the Lake Superior District and possibly in the Birmingham District. As it is now applied, it can be used only on iron ore of the variety known as "magnetite." This oxide of iron has such pronounced magnetic characteristics that large particles can be picked up with an ordinary horseshoe magnet. Since the particles of rock associated with the ore are not magnetic, it is a comparatively simple matter to separate the iron-bearing material despite a large proportion of rock in ore. Although this process cannot be used to concentrate hematite ore, which is non-magnetic, recent experiments have indicated simple methods of changing hematite to magnetite, after which magnetic concentration processes similar to those used on the natural magnetites can be applied.

In addition to the beneficiation processes described above, several other methods are used experimentally and may develop into important practical processes in the future. The quantities of low-grade ore in this country are almost unlimited, and large sums of money are being spent each year in the study of iron-ore beneficiation. Sufficient progress has already been made to justify the belief that long before the high-grade or direct-shipping ores of the country are exhausted, beneficiation operations will have been expanded to such an extent that the iron and steel industry can be supplied for an indefinite period of time with high-grade iron concentrate.

INCREASING IMPORTANCE OF CONCENTRATE

The ratio of shipments of iron concentrate to total iron-ore shipments shows a remarkably consistent rise since the beginning of the World War - from 10 percent in 1915 to a peak of 19 percent in 1936.[2] (See table 18.) The largest proportion of the iron-ore concentrate is shipped

[2] The percentage declined to 17 in 1937, despite an increase in the shipments of concentrate to a record peak, owing to a more rapid increase in the shipments of direct-shipping ore. The limited capacity of concentrating plants prevented a larger rise in shipments of concentrate. See also ch. III, pp. 27-9, including fig. 8.

Table 18.- CONCENTRATED ORE SHIPPED FROM IRON MINES IN THE UNITED STATES, 1915-38, BY STATE[a]

(Excludes ore containing 5 percent or more manganese)

Year	Minnesota[b]		New York, New Jersey, and Pennsylvania[c]		Alabama[d]		All other States		United States	
	Gross tons	Percent of U. S. total	Gross tons	Percent of U. S. total	Gross tons	Percent of U. S. total	Gross tons	Percent of U. S. total	Gross tons	Percent of total shipments of all ore
Total	116,960,313	68.1	31,648,268	18.5	14,606,039	8.5	8,459,663	4.9	171,674,283	13.6
1915	3,030,549	54.3	1,207,610	21.7	744,193	13.3	598,677	10.7	5,581,029	10.1
1916	4,576,249	56.5	1,779,258	21.9	996,344	12.3	753,160	9.3	8,105,011	10.4
1917	4,576,626	56.0	1,645,612	20.2	1,159,624	14.2	784,702	9.6	8,166,564	10.8
1918	5,012,060	63.6	1,360,625	17.3	986,630	12.5	522,255	6.6	7,881,570	10.9
1919	4,714,547	64.1	1,191,390	16.2	862,843	11.7	587,154	8.0	7,355,934	13.0
1920	5,050,968	59.3	1,723,576	20.3	1,073,770	12.6	666,524	7.8	8,514,838	12.3
1921	2,936,085	78.8	375,349	10.0	327,792	8.8	88,395	2.4	3,727,621	14.0
1922	4,621,202	69.8	824,800	12.5	803,369	12.1	373,773	5.6	6,623,144	13.1
1923	7,571,939	70.8	1,591,836	14.9	1,003,247	9.4	519,970	4.9	10,686,992	15.3
1924	5,134,264	72.4	797,146	11.2	751,774	10.6	409,355	5.8	7,092,539	13.6
1925	6,410,362	73.4	1,218,494	14.0	755,189	8.6	351,627	4.0	8,735,672	13.7
1926	5,439,499	65.0	1,676,132	20.0	633,692	7.6	622,506	7.4	8,371,829	12.1
1927	4,952,537	61.0	1,981,595	24.4	607,681	7.5	572,860	7.1	8,114,673	13.3
1928	5,485,096	63.6	1,903,913	22.1	649,645	7.5	582,677	6.8	8,621,331	13.6
1929	6,522,742	69.2	1,804,316	19.2	623,557	6.6	473,830	5.0	9,424,445	12.5
1930	6,316,111	70.4	1,747,281	19.5	586,878	6.5	323,618	3.6	8,973,888	16.3
1931	3,574,309	78.4	774,201	16.6	209,279	4.5	118,575	2.5	4,676,364	16.4
1932	292,458	71.8	83,810	20.6	31,218	7.6	-	-	407,486	7.6
1933	2,908,922	81.8	436,426	12.3	183,128	5.1	27,416	0.8	3,555,892	14.4
1934	3,245,788	78.3	682,824	16.5	213,091	5.1	3,887	0.1	4,145,590	16.1
1935	4,874,293	80.4	951,874	15.7	226,215	3.7	14,219	0.2	6,066,601	18.1
1936	7,510,837	77.8	1,739,701	18.0	380,544	3.9	27,617	0.3	9,658,699	18.8
1937	9,396,874	76.1	2,397,007	19.4	532,570	4.3	23,685	0.2	12,350,136	17.1
1938	2,805,996	58.0	1,753,492	36.3	263,766	5.4	13,181	0.3	4,836,435	18.3

[a] From reports of iron-mining companies to the U. S. Bureau of Mines.
[b] Produced principally by washing and jigging.
[c] Produced principally by magnetic concentration.
[d] Produced principally by washing.

from Minnesota,[3] whose share of the total shipments of concentrate gradually increased from 54 percent in 1915 to 76 percent in 1937. For New York, New Jersey, and Pennsylvania the percentage fluctuated between 10 and 24 prior to 1938 and in 1938 rose abruptly to 36.[4] Alabama's share of the total declined from 13 percent in 1915 to 5 percent in 1938. In all other States combined, the percentage has dropped from 11 in 1915 to less than 1 percent in the last 7 years. These figures indicate that the growth of iron-ore concentration in the United States in the past quarter-century was confined entirely to Minnesota, for shipments of

[3] In the Lake Superior District, iron ore is concentrated on a commercial scale only on the Mesabi and Cuyuna ranges of Minnesota.

[4] This increase in 1938 occurred despite a decline in the actual quantity of concentrate shipped from New York, New Jersey, and Pennsylvania, for the drop in concentrate shipments from all other States was much larger.

concentrate from other States were either decreasing or remaining virtually constant.

Almost all of the Minnesota concentrate is produced by washing and jigging methods. Although jigging is increasing in importance, washing still predominates.[5] It is the principal method of concentration in Alabama. In both Minnesota and Alabama practically all of the concentrate is produced from ores mined by open-pit methods. In New York, New Jersey, and Pennsylvania, the ore treated is from both open-pit and underground operations, and the concentrate is produced principally by magnetic separation.

ORE CONCENTRATION IN THE LAKE SUPERIOR DISTRICT

Virtually all of the ore concentrated in the Lake Superior District at the present time comes from open-pit mining operations where the mining cost is low enough to offset the added expense of operating concentrating plants. Most of the domestic ore deposits accessible to open-pit mining and amenable to the simpler methods of concentration are located on the Mesabi and Cuyuna ranges.

Not only did the Mesabi range account for about two-thirds of the total iron concentrate produced in this country in the past 15 years, but the possibilities of expanding concentration operations on this range are very much greater than in any other iron-mining district in the United States. It appears at the present time that the future continuation of the iron and steel industry along the Great Lakes and in the Pittsburgh District will depend upon the production of constantly increasing tonnages of concentrate in the Lake Superior District.

Grade and Quantity of Mesabi Ores

To understand the reasons for the probable importance of ore concentration on the Mesabi range, it is necessary to know something of the geology of the ore deposits and of the nature and extent of the iron formation. The Mesabi range stretches across northern Minnesota for about 100 miles and is roughly parallel to the north shore of Lake Superior, which is about 50 miles from the range.[6] It is believed that the iron formation was deposited millions of years ago on the bottom of an ocean that at one time covered the area now occupied by the north

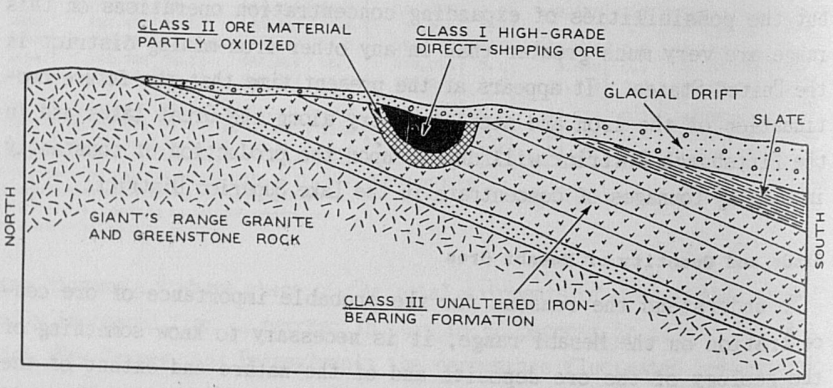
[5] In the 10-year period 1928-37, 82.2 percent of the concentrate shipped from Minnesota was produced by washing methods, 9.4 percent by jigging, 0.1 percent by magnetic concentration, 3.7 percent by sintering, and 4.6 percent by drying. See *Lake Superior Iron Ores: 1938* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), p. 313.

[6] See map of the Mesabi range in fig. 15.

central part of the United States. The iron contained in the original sediment has passed through many chemical and physical changes. The ocean which had originally covered the sediments receded, leaving them exposed; later, great glaciers moved down from the North, gouging the surface and scraping away much of the iron-bearing sediment. When the glaciers melted, they left behind great deposits of silt, sand, gravel, and boulders, which cover the original iron-bearing sediments to varying depths. There has been no violent ground movement in the Mesabi range area, and the old ocean deposits of iron-bearing formation still slope gently, regularly, and continuously toward the southeast.

The ore deposits on the Mesabi range may be grouped into three classes, as shown in figure 44. The Class III, low-grade, iron-bearing rock known as taconite contains what is left of the old, original iron-bearing sediment. Along its northern boundary the glacial drift is thin, and in some localities great areas of the iron formation are exposed. Toward the south, however, the drift becomes gradually thicker, and the iron-bearing formation slopes toward the southeast under this drift to an unknown distance. This low-grade, iron-bearing rock contains only

Figure 44.- GENERALIZED CROSS SECTION OF THE IRON FORMATION OF THE MESABI RANGE



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The iron-ore materials on the Mesabi range may be grouped into three classes according to the degree to which circulating water has softened the original iron formation, removed the silica, and left behind a concentration of iron oxide. Where this action was most pronounced there are now found deposits of Class I direct-shipping, high-grade ore assaying about 50 to 60 percent iron. Although this ore constitutes the bulk of the present shipments from Mesabi mines, it is being rapidly depleted. Surrounding the high-grade ore is the intermediate Class II ore assaying from 40 to 50 percent iron. Where this material is found, the original iron-bearing formation has been softened, but not enough silica has been removed to leave merchantable ore. The more readily concentratable portions of the Class II material are now being utilized on an increasing scale. Class III material constitutes the unaltered iron-bearing rock assaying from 20 to 40 percent iron. Billions of tons of this material are near enough to the surface to be mined by open-pit methods. Although it is not now mined on a commercial scale, it may be utilized in the future to supply a large part of the Nation's iron-ore requirements.

about 20 to 40 percent iron;[7] but in certain areas near the northern boundary where the glacial drift is thin, the action of circulating water has modified the older formations, softened them, in some places removed much of the silica, and has produced a high concentration of iron oxide. Where this action has proceeded sufficiently far there are now found large bodies of Class I high-grade ore. This material, assaying between 50 and 60 percent iron and from 3 to 10 percent silica, is acceptable for shipment to blast furnaces as mined, and it constitutes the bulk of the iron ore now produced at Mesabi mines.

Associated with the bodies of high-grade ore is the Class II medium-grade, intermediate material. Where Class II ore is found, the action of the circulating water has softened and, to some extent, altered the original ore-bearing rock but has not removed enough of the silica to produce merchantable iron ore. This material assays from 40 to 50 percent iron, and its quality and characteristics vary widely.

The approximate quantities of high-grade ore or concentrate contained in the three classes of ore materials on the Mesabi range were estimated in 1933 by the Mines Experiment Station of the University of Minnesota.[8] (See figure 45.) The Class I high-grade ore is being mined at a rapid rate, and about half of the original quantity of this ore has now been depleted, leaving about 1.0 billion tons still to be mined. If Class I ore were relied on to supply the entire demand for ore from the Mesabi range, it would be exhausted in about 30 years. Class II ore is being concentrated on a large scale, and about one-tenth of the original amount has been used up, leaving the equivalent of about 1.3 billion tons of high-grade concentrate still to be obtained. The Class III iron-bearing rock has hardly been touched; and counting only the part minable by open-pit methods, it contains enough high-grade concentrate - 57.2 billion tons - to maintain the present ore-shipping rate for many generations.

Outlook for Concentration of Mesabi Ores

Since about 1908 a steadily increasing amount of concentrate has been produced on the Mesabi range. About 25 percent of the ore shipped at

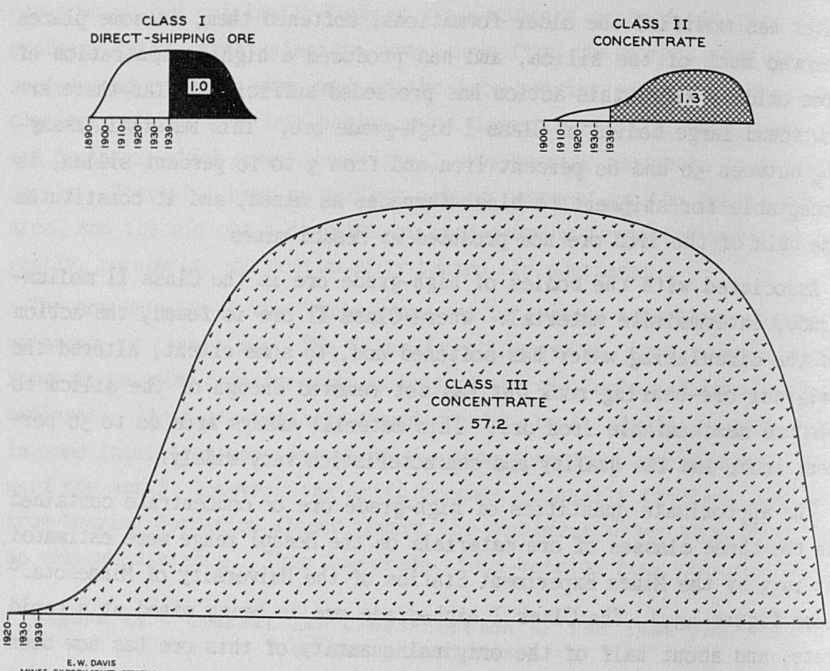
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[7] The percentages of iron contained, as used in this chapter, are computed on a dry basis.

[8] See E. W. Davis, "Iron Ore for Centuries in Mesabi Range; Fair Tax Key to Development," *Steel*, Vol. 92, No. 19 (May 8, 1933), pp. 13-4, 59-60.

It should be noted that the estimate of submarginal reserves on the Mesabi range reported by O. R. Kuhn (and used in ch. VII, fig. 47, and in table A-23) is lower than the estimate given in fig. 45. Both figures, however, indicate such a tremendous quantity of low-grade material that precise agreement of the estimates would be unlikely and is unimportant for practical purposes. Kuhn's data were used in ch. VII because they could be readily supplemented with comparable figures for other regions and areas.

Figure 45.- RESERVE ORE OF THE MESABI RANGE
(Billions of gross tons)



These diagrams indicate the relative importance of the three principal classes of ore materials on the Mesabi range. The white portions of the diagrams represent the amounts already mined; other portions represent the quantities of direct-shipping ore or high-grade concentrate obtainable from reserves of each of the classes of material.

The Class I high-grade ore is being mined at a rapid rate, and about half the original quantity of this ore has by now been depleted. Class II intermediate material is being concentrated on an increasingly large scale, and about one-tenth of the original amount has been extracted. The Class III iron-bearing rock has hardly been touched, and the quantity of high-grade concentrate shown in the diagram is only that portion obtainable from the unaltered iron formation within 400 feet of the surface.

the present time is concentrate that is produced by 24 large mills using Class II ore as their raw feed. Until about 15 years ago practically all of the concentrate from the Mesabi range was produced by washing methods. The wash ores are rapidly disappearing, however, and more elaborate concentrating methods are needed to process the remaining Class II materials.[9] The jigging method of ore treatment has increased notably in recent years, and in 1937 jigged concentrate amounted to

[9] About one-third of the crude ore fed to washing plants is discharged as tailings with an average iron content of about 22 percent. The tailings ponds contain a great accumulation of this material. Part of the wash-ore tailings is amenable to treatment by flotation for the recovery of high-grade concentrate. The development of successful methods for the treatment of tailings as they are produced will help to conserve some of the iron materials now wasted. Treatment of tailings has an advantage over the treatment of lean ore since there is no additional mining cost. See also John N. Searles, "Some Tests With Flotation on Mesabi Wash-Ore Tailings," *Engineering and Mining Journal*, Vol. 139, No. 6 (June 1938), p. 42.

14 percent of the total concentrate shipped from the Mesabi range. Jigs will certainly be used more extensively in the future either at existing washing plants or at separate jig plants, and several new types of jigs are being developed. Ores amenable to the jigging process are available at the margins of the deposits of direct-shipping and wash ores at nearly every pit.

Although all of the concentrate now being shipped is obtained from the Class II ore, a number of years ago an experienced mining company, after extensive investigations, constructed a large plant to concentrate the Class III iron-bearing rock.[10] This plant produced thousands of tons of high-grade concentrate and demonstrated that the low-grade iron-bearing rock could be concentrated by simple and effective processes that yielded a high-grade shipping product. After several years of operation, however, the plant was closed because no profit could be made at that time in selling concentrate in competition with the Class I direct-shipping ore.

It is expected that the production of concentrate will continue to increase as processes are gradually improved[11] and as mining companies, faced with fast-dwindling high-grade reserves, turn to lower-grade ores. The holdings of high-grade ore among the principal steel companies are not divided in relation to requirements. Some have a 50-year supply, while others have only a 5- or 10-year supply; hence the possibility of concentrating ores on an extensive scale is of more immediate concern to some companies than to others. Eventually, the steel companies will probably obtain more of their ore requirements by concentrating lean materials, drawing upon the Class I deposits mainly to meet an

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[10] For a description of this plant see Arthur B. Parsons, "Operations of the Mesabi Iron Co. - I," *Engineering and Mining Journal-Press*, Vol. 117, No. 4 (Jan. 26, 1924), pp. 157-64 and a continuation of this article, "Operations of the Mesabi Iron Co. - II," in Vol. 117, No. 5 (Feb. 2, 1924), pp. 202-10.

[11] It is expected that technical advances in the beneficiation of iron ore will permit labor as well as other economies in the use of each beneficiating method. The following quotation indicates how labor requirements have already been reduced at one large concentrating plant using the washing method:

"From time to time, as experience dictated, labor-saving devices have been introduced. The interior of the receiving bin was redesigned to eliminate square corners. The crude ore had a tendency to hang up and required poking to make it run. By rounding the corners this difficulty was overcome and the labor of two men was dispensed with. Large quantities of rock are removed from the ore as it passes over the 5-ft. pan conveyor and this work originally required two extra men. An air-operated ram was installed, at the side of the conveyor, which pushes and pulls the rock chunks off into pockets, with a subsequent saving in labor.

"During the first several years operation of the washing plant the railroad cars, which transport the concentrates, were moved under the chutes by means of pinch bars, and controlled by means of hand-brakes. At the present time the cars are moved by an electric vertical drum winch, and controlled by compressed air, conveyed to the brake cylinders through a rubber hose. The brakes are operated by a straight air valve located on the loading platform at the concentrate bin. These installations again saved the labor of two men." See H. C. Bolthouse, "Beneficiation of Hill-Trumbull Mine Ores," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929), p. 756.

abnormally high demand or to obtain material for blending with concentrate that has an excessive silica content. In this way the need for excessive concentrating-plant capacity can be avoided, and the life of the high-grade ore reserves will be prolonged.

As indicated by typical operating labor costs for 1936, the labor requirements for mining and concentrating Class II materials are 2 to 6 times as high as for mining Class I ore, depending on the method required;[12] the labor requirements for mining and concentrating Class III materials are about 7 times as high as for mining Class I ore. Only about 25 percent of the Class II material is amenable to simple washing methods of concentration, which require about 2 man-days per carload. The remaining 75 percent of the Class II material now requires jigging or roasting, and all of the Class III material would require much more elaborate processes. The concentrate that will be produced from most of the low-grade ore, for example, will be too fine for blast-furnace use, and it will be necessary to agglomerate this concentrate to produce a satisfactory furnace ore.[13] Moreover, about 2 tons of crude materials must be mined for each ton of Class II concentrate and about 3 tons for each ton of Class III concentrate. Mining the latter will also be more difficult because of the greater hardness of the unaltered formation. As more and more ore is concentrated, therefore, unit labor requirements would be increased.

The rapidity with which the Class II and Class III materials will be concentrated, however, depends not only on the advance in the art of beneficiation but on many economic factors as well. Among the latter are the factors affecting the demand for iron ore (which are considered in the next chapter), the method of taxation, and the conditions surrounding the leasing of mineral deposits. Insofar as the demand for Lake Superior ore increases, the utilization of the low-grade ores will

[12] As noted in ch. III, the output of merchantable ore per man-hour during 1923-37 was twice as high at open-pit mines in Minnesota that produced direct-shipping ore as at open-pit mines that concentrated their product before shipment. (See table A-9.) Practically all of the concentrate was produced by simple washing methods from the higher grades of Class II material.

[13] If it is possible to change the smelting furnace to suit the fine ore rather than to change the ore to suit the customary blast furnace, the utilization of the low-grade ore will be greatly stimulated. Considerable experimental work has been done, with encouraging results, in the development of a reverberatory smelting process for iron ore similar to the reverberatory smelting process used for copper ores. The fine concentrate mixed with coal dust is fed in along the side walls of the reverberatory furnace, and the charge is melted down as with the copper ores. The slag and metal are tapped off separately, and waste-heat boilers recover the heat loss in the furnace gases. It is proposed to generate electric power from this waste heat, which will be used in electric furnaces to convert the furnace metal into steel. This process has not been put into commercial operation, but several hundred tons of metal have been made, some of which has been converted into steel and rolled into bars. The commercial development of this process would make possible the utilization of the fine ores that, at the present time, must be agglomerated.

be stimulated; but if requirements decline, the necessity for utilizing the low-grade materials will be postponed.[14]

The present ad valorem tax system in Minnesota is considered by some observers to be adverse to a more rapid utilization of low-grade ores.[15] The ad valorem tax increases with the value (and hence the grade) of ore and is assessed annually on mineral-land holdings. Its effect is to encourage companies to mine their high-grade ore deposits rapidly and to discourage them from mining and concentrating their low-grade ores that are taxed at a lower rate. Thus mining the low-grade concentrating ores would simply prolong the time during which taxes would have to be paid on the high-grade, more valuable ore.

Conditions surrounding the leasing of iron deposits at present also hasten the exploitation of the highest-grade ore.[16] Many of the ore lands were leased long ago at the relatively low royalty fee of $0.25 a ton without any provisions requiring the extraction of lower-grade ores. Newer leases have increased the royalty fees and require a more thorough exploitation of the deposits. Many of the old leases are due to expire within the next 15 years, and the royalty fees are almost certain to be increased. Hence the operators of these properties feel the necessity of extracting the remaining high-grade ore as rapidly as possible before the expiration of the leases.

The recently announced policy of the Oliver Iron Mining Company, a subsidiary of the United States Steel Corporation, to sell iron ore on the open market[17] may also prove to be an important factor in stimulating the more rapid mining of the highest-grade deposits and in retarding expansion in the mining and concentration of low-grade ores. Heretofore the Oliver Iron Mining Company had mined ore solely for the use of the United States Steel Corporation. The change in policy may be significant because with its large holdings of the highest-grade

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[14] It is not possible, for example, to indicate the probable effect of the Great Lakes-St. Lawrence deep waterway upon the domestic iron and steel industry. Although it does not appear likely that new markets will be opened by the waterway, it will make possible the easy importation of foreign ores for use at Lakes furnaces. Should such importations increase notably and the demand for Lake Superior ores decline, the necessity for utilizing low-grade domestic iron ores would be postponed.

[15] See Roy G. Blakey and Associates, *Taxation in Minnesota* (Minneapolis, Minn.: University of Minnesota Press, Studies in Economics and Business No. 4, Nov. 1932), p. 58.

[16] *Ibid.*, pp. 261-2.

[17] The following advertisement appeared in the *Skillings' Mining Review*, Vol. 28, No. 39 (Jan. 20, 1940), p. 12:

"Oliver Iron Mining Company. Subsidiary of United States Steel Corporation. Producer of Iron Ores from Lake Superior District. Mesabi Ores for Sale on Long or Short Term Contracts. General Offices, Wolvin Building, Duluth, Minn."

See also J. F. Froggett, "Touch and Go," *Daily Metal Trade*, Vol. 30, No. 19 (Jan. 27, 1940), p. 6.

ore deposits the corporation is in a very strong competitive position. Information is not available regarding the tonnage that will be offered to purchasers; but should large quantities of ore be sold on the open market at prices substantially lower than those that have prevailed for the past 20 years, the independent companies producing ore that requires concentration before shipment may not be able to continue their operations and less low-grade ore will be mined.

Outlook for Ore Concentration on the Cuyuna Range

An important increase in the production of concentrates is expected on the Cuyuna range in Minnesota, although on a much smaller scale than on the Mesabi range. The Cuyuna range deposits contain both iron and manganese oxides. These ores range from iron ore containing practically no manganese to ferruginous ore containing 25 to 30 percent manganese and 20 to 30 percent iron. Most of the ore shipped at the present time from the Cuyuna range, known as "manganiferous iron ore", contains from 5 to 10 percent manganese and from 35 to 45 percent iron. Although a large proportion of the ore shipped from this range has been beneficiated in recent years, the earlier shipments were largely direct-shipping ore. The quantity of high-grade ore left on the Cuyuna range that does not require beneficiation is very small, but the quantity of low-grade ore that may be beneficiated is large. An accurate estimate of the tonnage of low-grade ore on the Cuyuna range cannot be made without much additional exploration because the formations are twisted, folded, and irregular. It is roughly estimated, however, that about 100 million tons of material of shipping grade, mostly in the form of concentrate, can be produced from the Cuyuna deposits.

The manganiferous iron ores on the Cuyuna range have certain characteristics that account for the beneficiation methods now in use. In general, the ore is high in free moisture and in water that is chemically combined with the oxides. The total moisture content often amounts to 30 percent of the weight of the ore as mined, and a considerable proportion of the moisture can be removed by passing the ore through rotary driers. Sintering removes practically all of the water and has the added advantage of materially improving the structure of the ore. The Cuyuna ores normally contain a substantial amount of fine material, the coarser lumps being usually high in manganese and the finer particles high in iron. It is therefore possible to produce various grades of iron and manganiferous iron ore from this material by crushing, screening, washing, drying, or sintering.

The manganese ores are commonly called "the black ores." Some of these ores with sufficiently high manganese content to be suitable for direct shipment as ferro-grade manganese ore have been found occasionally in small ore bodies. A large proportion of the manganese ores, however, is high in silica, and requires beneficiation for the production of both ferro- and spiegel-grade ores. Considerable experimental work has been done in processing this material which offers the interesting possibility of a domestic source of large quantities of manganese.

In the meantime, however, the Cuyuna range will continue to be a large shipper of iron and manganiferous iron ore, largely in the form of concentrate, for an indefinite number of years.[18]

OUTLOOK FOR THE CONCENTRATION OF ALABAMA ORES

As previously noted, the production of concentrate in Alabama has declined in the past 20 years. (See table 18.) This is because the brown ores concentrated by the washing process are nearing exhaustion, and the red ore which exists in large quantities in the Birmingham District is very difficult to concentrate. The red ore assays only about 35 percent iron and contains about 35 percent other material, principally silica, lime, and alumina. The ore consists of small, rounded grains of hematite which cluster around nuclei of silica particles. These grains are loosely cemented together by soft, iron-bearing material, containing most of the lime in the ore. To concentrate this material, it must be crushed very fine and much of the silica removed by careful classification and tabling operations. Much work has been done to develop a process that can be used commercially and a large concentrating plant is now being erected. Experimental results show that it is possible to produce red-ore concentrate assaying over 50 percent iron and approximately 20 percent silica, lime, and alumina, with an iron recovery of over 80 percent and a concentration ratio of less than 2 tons of crude ore to 1 ton of concentrate.[19]

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[18] Large deposits of low-grade iron ore are also available in Michigan and Wisconsin. The development of large-scale operations for the concentration of low-grade ores in these States is a more remote possibility than in Minnesota because a smaller proportion of the ore is available for open-pit mining. Nearly all of Michigan's potential ores are fine-textured and will require fine grinding to free the valuable iron minerals from the gangue. Some thought has been given to the possibility of using flotation to bring about this separation. If this process becomes practicable, the fine concentrates would then have to be sintered before smelting unless they are smelted in a reverberatory furnace instead of the conventional blast furnace. See also W. E. Keck, "Michigan's Potential Iron Ores," *Engineering and Mining Journal*, Vol. 139, No. 4 (Apr. 1938), pp. 46-8.

[19] See B. W. Gandrud, A. C. Richardson, and B. S. Followill, *Classification and Tabling of Alabama Red Iron Ores* (U. S. Dept. Int., Bur. Mines, Report of Investigations 3224, mimeo., Mar. 1934); also F. D. DeVaney, B. W. Gandrud, and W. H. Coghill, *Gravity Concentration of Alabama Oolitic Iron Ores* (U. S. Dept. Com., Bur. Mines, Report of Investigations 2937, mimeo., May 1929).

In the past, wage rates have been relatively low in the Birmingham District; and coal, coke, and iron ore could be produced and assembled so cheaply that pig iron made from the unconcentrated red ore could compete with that produced from the northern furnaces. In recent years, however, wage rates in Alabama have advanced,[20] and the resulting rise in the cost of producing pig iron in the Birmingham District has increased the importance of finding a practicable method of cheaply concentrating the red ores of this district. Without concentration, the amount of coke consumed in the production of a ton of pig iron cannot be reduced much below 2,500 pounds, but after concentration and sintering of the concentrate it could be reduced to less than 2,000 pounds per ton of pig. The problem is receiving very careful consideration at the present time, and it appears likely that the concentration of Alabama iron ores will increase. The total reserve tonnage of available ore is estimated to be about one billion tons (see table A-27), sufficient to maintain present production rates in the Birmingham District for a great many years.

OUTLOOK FOR BENEFICIATION AT THE EASTERN MAGNETITE MINES

The iron ores of New Jersey, which are nearly all magnetite, have been mined and concentrated almost continuously since 1710. The earlier methods of concentration were very crude, consisting chiefly of hand sorting or picking, but the present plants are equipped with wet and dry magnetic separators, and some of the fine concentrate is sintered. The iron ore occurs in numerous small deposits with little outcrop but extending to great depth and assaying from 40 to 60 percent iron. The estimated workable quantity of this material amounts to 600 million tons, from which 400 million tons of high-grade concentrate can be produced. Although there has been no notable expansion in iron-ore concentration in this district for many years, the reserve tonnage is sufficient to maintain present shipping rates for many years or to increase these rates if required. An important recent development in the beneficiation of magnetites in this State is the production of sinter with a very high iron content and low in silica. This concentrate has been used in the past 2 or 3 years with effective results and has greatly reduced blast-furnace coke consumption.[21]

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[20] W. R. Curran, *Trend of the Southern Pig-Iron Business* (American Institute of Mining and Metallurgical Engineers, Tech. Pub. No. 851, 1937); also J. M. Hassler, *Offsetting Increased Labor Cost in Southern Blast-Furnace Operation* (American Institute of Mining and Metallurgical Engineers, Tech. Pub. No. 854, 1938).

[21] See C. E. Agnew, "Benefits From the Use of High-Iron Concentrates in a Blast Furnace," *Transactions of the American Institute of Mining and Metallurgical Engineers; Iron and Steel Division*, Vol. 131 (1938), pp. 116-20.

Until there is a shortage of Class I and Class II concentrate from the Lake Superior District or until the steel companies feel a much greater need of increasing their ore reserves in the East, no large expansion of iron-ore concentration in New Jersey is to be expected. Transportation costs are very important in determining the value of the New Jersey ores, since the concentration plants are 400 miles all-rail from Pittsburgh. Changes in freight rates favoring the New Jersey ores as against the Lake Superior ores would stimulate New Jersey operations, but no reduction in mining or concentration costs is likely to be of sufficient magnitude to bring about greatly increased production in this district. The ore is mined by underground methods requiring considerable labor, and no material reduction in mining cost is probable without a reduction in labor rates, which is not anticipated. The cost of concentrating the ore is only about $0.20 per ton, and although improvements in metallurgy will undoubtedly reduce this cost to some extent, savings made in this small cost cannot radically affect the total cost of producing concentrate and shipping it to the furnaces.

As in New Jersey, the iron ores of New York State are principally magnetite assaying between 40 and 60 percent iron. The ore is mined by underground methods and is concentrated to produce a shipping product, largely sinter, assaying more than 68 percent iron. The reserves of iron ore in New York are estimated at about 900 million tons, from which approximately 600 million tons of concentrate can be produced. The mining and concentration of this material was first begun in 1756, and operations have been practically continuous since that time. The annual production of concentrate has seldom exceeded one million tons per year, and there is available a sufficient quantity of ore to keep the industry active for many years to come.

As with the New Jersey ores, freight rates limit the amount of concentrate that can be shipped out of the State. It is significant, however, that late in 1937 a cargo of New York ore was shipped by canal barge and lake freighter to Cleveland, thus entering a market normally supplied by the Lake Superior ores.[22] This is believed to be the beginning of a trend that may become more important in the future, for a large steel company has recently acquired iron-ore properties in northern New York and is expanding ore-concentrating and -sintering facilities. The high iron content of the sinter produced permits economies both in transportation and smelting. Any material increase in the cost of delivering

[22] See Robert H. Ridgway and H. W. Davis, "Iron Ore, Pig Iron, Ferro-Alloys, and Steel," *Minerals Yearbook, 1938* (U. S. Dept. Int., Bur. Mines, 1938), p. 503; also "Revived Interest in Eastern Mines," *Steel*, Vol. 105, No. 6 (Aug. 7, 1939), p. 31.

Lake Superior ores to the blast furnaces in the Pittsburgh District will further stimulate concentration operations in New York. The cost of concentrating the ore is very low, but since it must be mined by underground methods, any material reduction in the cost of producing concentrate in this district is hardly to be expected.

Though iron ore has been mined and concentrated in Pennsylvania for a great many years, the mine near Cornwall is the only consistent shipper at the present time. The ore is magnetite assaying about 40 percent iron and is mined both by open-pit and underground methods. The crude ore is transported a short distance to Lebanon, Pennsylvania, where it is concentrated and sintered, most of the sinter being shipped to Bethlehem, Pennsylvania. The amount of reserve ore in the Cornwall District is definitely limited, amounting to around 70 or 80 million tons, from which about 35 or 40 million tons of concentrate can be produced. Most of the open-pit ore has been mined already, and most of the remaining ore must be mined by underground methods. The cost of concentrating this ore is very low, not exceeding $0.20 per ton, and the possibility of materially reducing this cost by future improvements in concentration practice is not great. It is expected that Pennsylvania will produce concentrated ore at about the same rate as during the past few years until the Cornwall ore is exhausted.

INFLUENCE OF IRON-ORE IMPORTS

Only a small amount of foreign ore reaches smelting plants on the Atlantic coast each year, and it is unlikely that imports will ever become an important source of the iron-ore requirements of the larger iron- and steel-producing centers.[23] Even with the completion of the Great Lakes-St. Lawrence deep waterway, the cost of delivering ore from Sweden, Africa, South America, or Cuba is likely to be too high to compete seriously with the domestic, direct-shipping ore or concentrate delivered to the Pittsburgh District or along the Great Lakes.

Some competition in the domestic market is anticipated, however, from the Canadian ores in the Lake Superior District. These ores are low-grade and require concentration, just as do the low-grade ores on the Mesabi range. Up to the present time, very little iron-ore concentrate has been produced in Canada, because Canada has no large steel industry and because the steel industry in the United States has been amply supplied with high-grade ore and concentrate from this country. Recently,

[23] See H. M. Roche, "The Iron Ores of New Jersey," *The Iron Age*, Vol. 139, No. 7 (Feb. 18, 1937); also Charles Hart, "Foreign Iron Ores," *Transactions of the Iron and Steel Institute, Iron and Steel Division*, Vol. 84 (1929), pp. 7-35.

however, the Ontario and Canadian governments have offered a bounty for a 10-year period of approximately $1.00 per ton on concentrate produced in Ontario.[24] This, together with a liberal tax policy relative to iron ores in Canada, has attracted the attention of some of the larger ore producers of Minnesota and Michigan.

To summarize, domestic iron-ore requirements of the future will probably be met largely by: (1) the Lake Superior ores, principally from the Mesabi range with a greater proportion of concentrates; (2) the New Jersey and New York State concentrates; and (3) Alabama ores, both concentrated and natural. Thus iron-ore beneficiation is destined to play a much more important role in our economy in the future than it has done in the past.

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[24] "Provincial Bounty to Apply to Iron Mines on Application," *The Northern Miner* (Toronto, Canada, Feb. 25, 1937), pp. 17 ff.; see also *Skillings' Mining Review*, Vol. 26, No. 4 (May 22, 1937).

CHAPTER VII

EMPLOYMENT PROSPECTS IN IRON MINING*

The rise in output per worker in iron-ore mining over the past 57 years, the principal causes of this development, and its effect upon employment opportunities have been reviewed briefly in the preceding chapters. Will the trend in output per man continue upward? What is the outlook for employment in iron mining over the next decade? And over a longer period? The answers to these problems are governed by answers to several other questions of great importance. First, what is the extent and character of American iron-ore resources? Second, will the demand for iron ore increase, remain stationary, or decline, and at what rate will probable changes take place? Third, how much further can mechanization, with attendant declining unit labor requirements, be carried?

SOURCE OF FUTURE IRON-ORE SUPPLIES

An important clue to the future extent and location of iron mining in the United States is the nature of its iron-ore reserves. An analysis of the size, quality, and accessibility of these reserves indicates that they are sufficient to meet the needs of domestic blast furnaces for at least several generations. The best deposits likely to be mined in the next decade, moreover, will present no new major problems in mining and beneficiation.

Domestic Reserves of Iron Ore Are Adequate for Many Years

It is estimated that this country has about 5 billion gross tons of ore reserves sufficiently high grade and accessible to be profitably mined under present economic and technical conditions. This is about twice as much ore as has been produced in the United States since 1810. If it is mined at the same rate as during 1922-30, which, as explained later, appears probable, it is sufficient to last for about 70 years. Further discoveries may add somewhat to the present-known available reserves of relatively high grade ore. Beneficiation progress, as reviewed in the preceding chapter, is expected to make available a substantial part of an estimated additional 73 billion tons of submarginal reserves that cannot now be mined economically. Thus, for the country

*By N. Yaworski and O. E. Kiessling.

as a whole, the ore reserves are sufficient to support the iron-mining industry for a long period.[1]

Although iron deposits are widely distributed throughout the United States (see figure 46), over 80 percent of the available reserve is located in the three major areas (see figure 47 and table 19) that produced 97 percent of the merchantable ore in the past quarter-century. These three regions - the Lake Superior District, the Birmingham District, and the Northeastern District - produced 85 percent, 9 percent, and 3 percent respectively of the total output of merchantable ore in this country since 1915. The ore deposits in each of these areas have been mined for more than half a century, during the course of which costly mining, transporting, and ore-smelting facilities have been developed and well established. Although prior to 1915 the percentage of total production contributed by the mines in each of these districts changed notably, since 1915 the proportions have remained virtually constant.[2] In view of the size, character, and availability of the

Table 19.- COMMERCIAL IRON-ORE RESERVES IN 1938 AND ORE PRODUCED DURING 1915-38, BY PRINCIPAL AREA

Area	Commercial ore reserves, 1938[a]		Merchantable ore produced, 1915-38[b]	
	Gross tons (millions)	Percent of total	Gross tons (millions)	Percent of total
United States	5,038.0	100.0	1,252.3	100.0
Lake Superior District	1,421.8	28.2	1,060.2	84.7
Birmingham District[c]	1,003.0	19.9	115.6	9.2
Northeastern District	1,658.0	32.9	40.5	3.2
All other areas	955.2	19.0	36.0	2.9

[a] Excludes reserves that are submarginal either for economic or technical reasons. See table A-23 for sources and supplementary explanations.

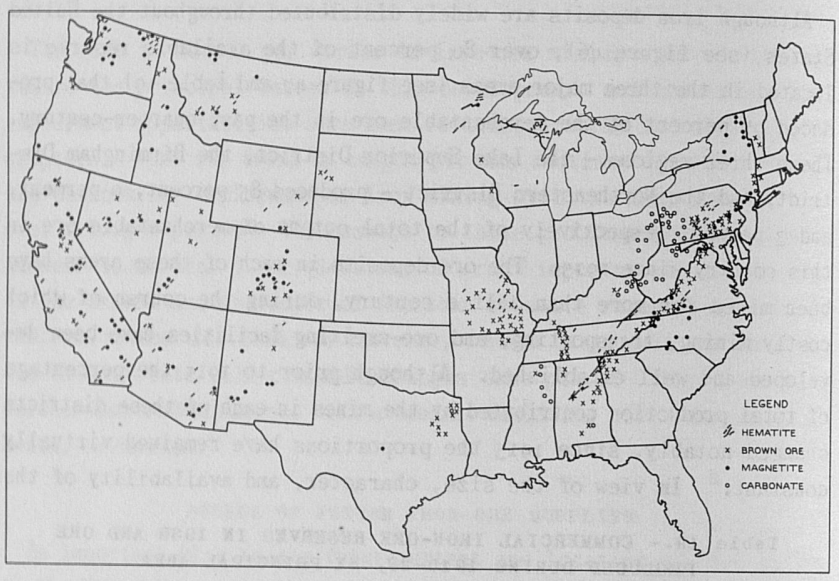
[b] From reports of iron-mining companies to the U. S. Bureau of Mines.

[c] Includes Bibb, Blount, Chilton, Jefferson, Shelby, and Tuscaloosa Counties in Alabama.

[1] Although the total potential tonnage of iron in present commercial and submarginal ores is large, it is important to note that the use of the submarginal ores will require a larger per-unit expenditure of labor and energy than is required for present commercial ores. Thus problems of the competitive position of the domestic iron industry and of the conservation of the high-grade reserves are more immediate than the over-all tonnage figures suggest.

[2] See fig. 9 on p. 32. Fluctuations since 1915 have been essentially temporary and are mainly attributable to the greater responsiveness of open-pit operations to changes in demand. Thus in 1932 when demand was greatly curtailed open-pit mines reduced their production to a greater extent than underground operations. Since most of the open-pit mines are in Minnesota, this was reflected in a temporary decline in the share of the total output produced by this State. In times of slack demand for iron ore in the future, Minnesota will probably contribute, as in the past, a somewhat smaller proportion of the total production because a large proportion of the ore deposits that are now developed and that will be developed can be mined by open-pit methods.

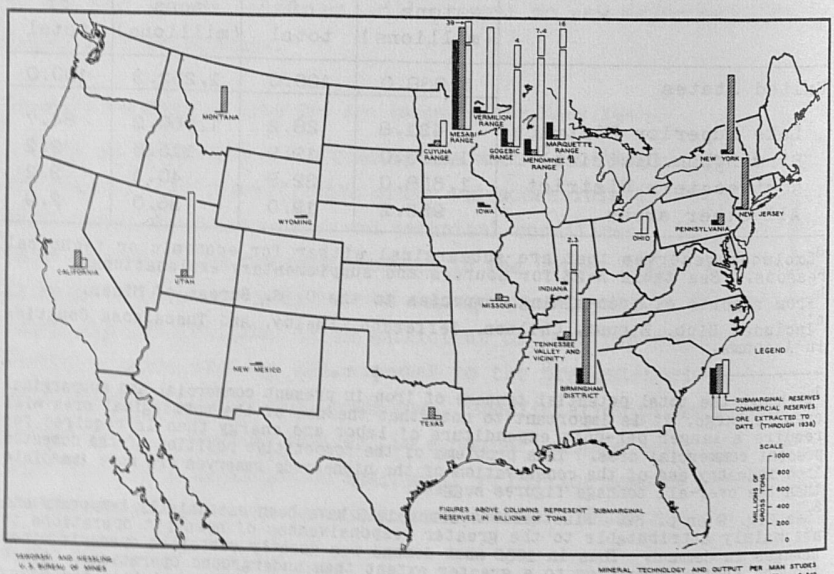
Figure 46.- DISTRIBUTION OF IRON-ORE DEPOSITS IN THE UNITED STATES, BY KIND OF ORE



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Figure 47.- ESTIMATED IRON-ORE RESERVES IN 1938 AND ORE PRODUCED THROUGH 1938 IN THE UNITED STATES



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ore deposits in each district and the existing facilities for exploiting them, it is expected that substantially the same relationship will continue for at least the next decade. This is an important consideration, for, as noted in chapter III,[3] the unit labor requirements of the three districts are considerably different, and if any important change in each district's share of the total production were anticipated the estimate of future employment would have to be modified accordingly.

Lake Superior District.- This district has supplied about 85 percent of all the iron ore produced in the United States in the past quarter-century. Since the beginning of mining, about 1854, it has produced over 1.7 billion tons of merchantable ore. It is estimated that the district still has reserves of at least 1.4 billion tons of ore of present commercial grade and many more billions of tons of submarginal ore. (See table 20.)

Table 20.- ESTIMATED IRON-ORE RESERVES IN 1938 AND ORE PRODUCED THROUGH 1938 IN THE LAKE SUPERIOR DISTRICT, BY STATE AND RANGE[a]

State and range	Estimated ore reserves, 1938				Merchantable ore produced through 1938		
	Commercial		Submarginal		Date of first production	Gross tons (millions)	Percent of total
	Gross tons (millions)	Percent of total	Gross tons (millions)	Percent of total			
Lake Superior District	1,421.8	100.0	67,660	100.0	-	1,724.8	100.0
Michigan and Wisconsin							
Marquette	49.9	3.5	16,000	23.6	1854	197.6	11.5
Menominee	58.0	4.1	7,360	10.9	1877	182.9	10.6
Gogebic	46.2	3.2	4,000	5.9	1884	209.5	12.1
Minnesota							
Vermilion	14.4	1.0	1,000	1.5	1884	65.7	3.8
Mesabi	1,191.0	83.8	39,000	57.7	1892	1,043.7	60.5
Cuyuna	62.3	4.4	300	0.4	1911	25.4	1.5

[a]See table A-23 for details and sources.

The 1.4 billion tons of ore of present commercial grade are situated largely on the Mesabi range and most of this material does not require concentration before shipment and can be mined by economical open-pit methods. At the annual average rate of production that prevailed during 1922-30 it is sufficient to last for at least 26 years. The estimate is probably low, however, for it is based on conservative figures of high-grade ore proven to exist by drill holes. Further discoveries will probably add somewhat to the present-known tonnages. Leith and Liddell, for example, hold that future discoveries are likely to add 15 percent to the high-grade reserves on the Mesabi range and to increase the expected productive life of the Michigan and Wisconsin iron

[3]See pp. 31-7.

ranges as much as 40 percent.[4] Thus it is clear that reserves of present commercial ore in the Lake Superior District are enough to assure the leadership of this district for at least the next 30 years. Future beneficiation progress, moreover, will doubtless lengthen the estimated life of the high-grade ore reserves insofar as it makes deposits of submarginal ores economic sources of supply.

As in the past, the high-grade, direct-shipping ore in the Lake Superior District will be gradually depleted and there will be need for utilizing ores that require beneficiation. An increasing proportion of the crude ore will be mined by the open-pit method with its characteristic low unit labor requirements. For the next decade, and until much leaner ore is beneficiated than at present, the labor economies due to the expansion of open-pit mining and to technological advances at both open-pit and underground mines will probably offset the added labor requirements for ore beneficiation, and the upward trend of output per worker will therefore continue.

Birmingham District.- Ore of present commercial grade in the Birmingham District of Alabama is estimated at about 1 billion tons. This represents material that is obtainable from above the 3,500-4,000-foot level. The ultimate recovery probably will be less than 1 billion tons because some ore must be left in pillar supports. These reserves are sufficient to last over 125 years at the average annual rate of production for 1922-30. In addition, the Birmingham District contains about a billion tons of submarginal reserves, including siliceous ores and ore in beds more than 4,000 feet below the surface.

About 6.3 percent[5] of the ore mined in this district in the past quarter-century was brown ore. This ore contains so much waste material that, despite open-pit mining and simple washing methods of concentration, about twice as many man-hours are required to produce a ton of merchantable ore as to produce a ton of direct-shipping red hematite ore mined by underground methods. The brown-ore deposits in this district are now almost depleted, however, and the remaining reserves consist of red hematite ore that must be mined underground. As noted in the preceding chapter, considerable interest is being shown at present in the concentration of Alabama red ores. Cheap power, needed for crushing the crude ore to fine sizes, is available from hydroelectric projects

[4] Kenneth Leith and Donald M. Liddell, *The Mineral Reserves of the United States and Its Capacity for Production* (National Resources Committee, mimeo., Mar. 1936), p. 98.

[5] Brown-ore concentrate produced in the Birmingham District declined from 11.3 percent of the total quantity of merchantable ore produced in 1915 to 4.5 percent of the total in 1938. Data are from reports of iron-mining companies to the U. S. Bureau of Mines.

in the neighboring Tennessee Valley, and may aid this development. Any large increase in ore concentration in this district would tend to reduce output per man. In the next decade, however, continued technological advances are expected to be of greater importance, and output per worker will show a moderate increase.

Northeastern District.- The estimated available ore reserves of New York, New Jersey, and Pennsylvania exceed 1½ billion tons of crude ore from which about a billion tons of high-grade concentrate can be produced. Since the average annual future production of concentrate from this region is estimated at less than 5 million tons, these reserves are sufficient for a very long period. Since less than 5 percent of the annual output of merchantable ore is produced in the Northeastern District, even a substantial increase in production would not greatly alter the proportions of the total output contributed by the three major districts. As in Alabama, most of the future mining in the Northeastern District must be by underground methods and output per man will continue to be relatively low.

Other Areas.- Iron-ore reserves are also found in many other sections of the United States. At least 13 States west of the Mississippi River have considerable deposits of iron ore, and a few of these are being mined. In general, however, the deposits in other areas are scattered, difficult of access, and uneconomic at present. Some development of these reserves may follow the extension of railroad lines or the erection of smelting facilities on the West Coast. These are possible developments that may increase output in the Western States, but it is unlikely that production will be large.

Successful Competition by Foreign Ore Unlikely

Imports of iron ore have thus far been of negligible importance and are not likely to make serious inroads into the domestic market. Although foreign ore amounting to 1 to 3 million tons per year is used in the blast furnaces on the Atlantic seaboard, it cannot compete successfully with the Lake Superior ores in the iron and steel districts farther inland.

The nearest foreign reserves of iron ore are in Canada. Those in the central provinces consist mostly of the low-grade material (described as Class III in chapter VI) which is found in much larger quantities on the Mesabi range. One of the nearest important deposits of iron ore is located at Belle Isle, Newfoundland, and is estimated to contain from 3 to 4 billion tons, but the high phosphorous content of the Newfoundland ore is not suited to the open-hearth process of steel manufacture in

the United States. The ore must be mined from underground workings extending underneath the ocean floor, and the deposits are 800 miles farther from Lake Erie ports than are the Lake Superior deposits. Hence it is not likely that this source will supply inland American blast furnaces in the near future.[6]

High-grade iron ores from more remote sources, principally Cuba, Chile, Brazil, and the Scandinavian Peninsula, will doubtless be imported in the future. As in the past half-century, however, the imported ores will probably be used mainly by the blast furnaces along the Atlantic seaboard and cannot compete seriously with domestic mines as long as large quantities of high-grade, direct-shipping ore are available from the Lake Superior District. As was noted in chapter VI, moreover, the completion of the Great Lakes-St. Lawrence deep waterway will not materially change this situation.

FUTURE DEMAND FOR IRON ORE

With domestic reserves ample for at least several generations, employment opportunities in the iron-ore mining industry will depend primarily on the demand for ore. The need for ore, in turn, will hinge mainly upon trends in consumption by the major iron-using industries and upon the extent to which ferrous scrap will supplant newly mined ore.

Growth of Demand for Iron and Steel Products Slackens

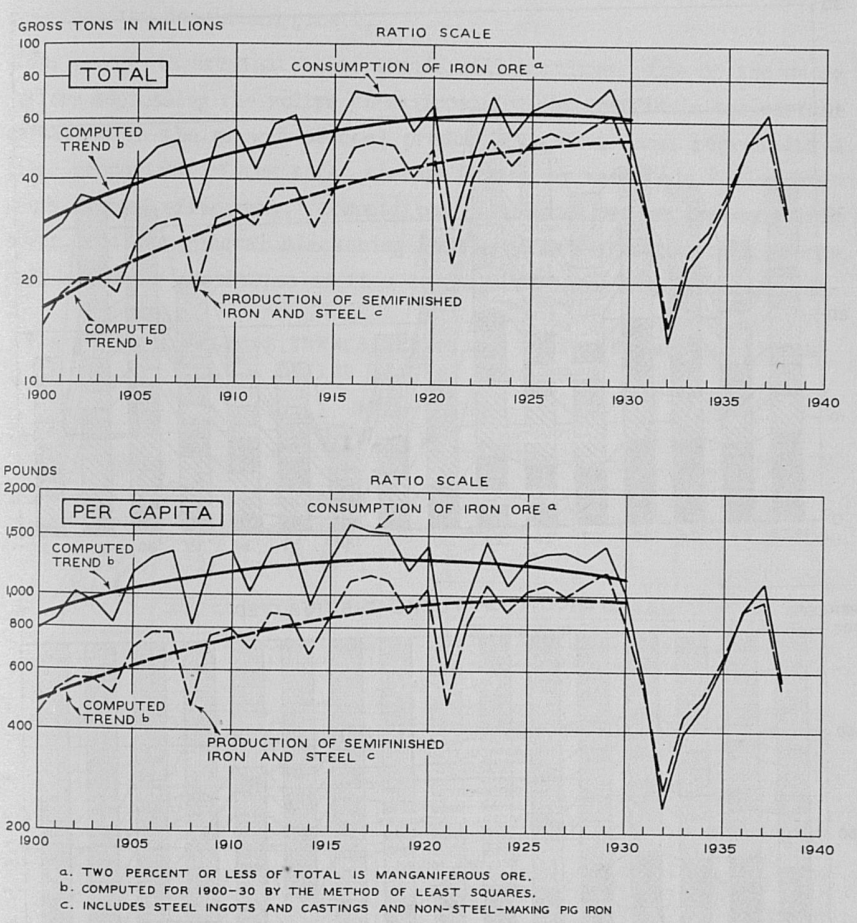
Prior to the twenties the growth of output of semifinished iron and steel products was marked and exceeded the rate of population increase. In the post-war period, however, the rate of production growth slackened notably. Also, as the relative decline in the growth of population was less pronounced, per-capita production of semifinished iron and steel actually decreased.[7] (See figure 48.)

Barring the hazard of participation in a general war, it is probable that the slackened or arrested rate of growth in the demand for iron and steel products will continue during the next decade, for there is little indication of greater demand from the principal consumers of iron and steel. In the 16-year period 1923-38 the three major users of iron and steel were the railroad, automobile, and construction industries and they consumed 50 percent of all rolled-steel products. (See figure 49.) That an increase in the rate of iron and steel consumption

[6] Cf. Fayette S. Warner, *The Future Movement of Iron Ore and Coal in Relation to the St. Lawrence Waterway* (Philadelphia, Pa.: University of Pennsylvania Press, 1930), pp. 77-86.

[7] The trend lines in fig. 48, representing the consumption of iron ore and the production of iron and steel, were purposely not extended beyond 1930 so as not to reflect the unusually low demand during the ensuing depression years.

Figure 48.- CONSUMPTION OF IRON ORE AND PRODUCTION OF SEMIFINISHED IRON AND STEEL IN THE UNITED STATES, 1900-38



a. TWO PERCENT OR LESS OF TOTAL IS MANGANIFEROUS ORE.
b. COMPUTED FOR 1900-30 BY THE METHOD OF LEAST SQUARES.
c. INCLUDES STEEL INGOTS AND CASTINGS AND NON-STEEL-MAKING PIG IRON

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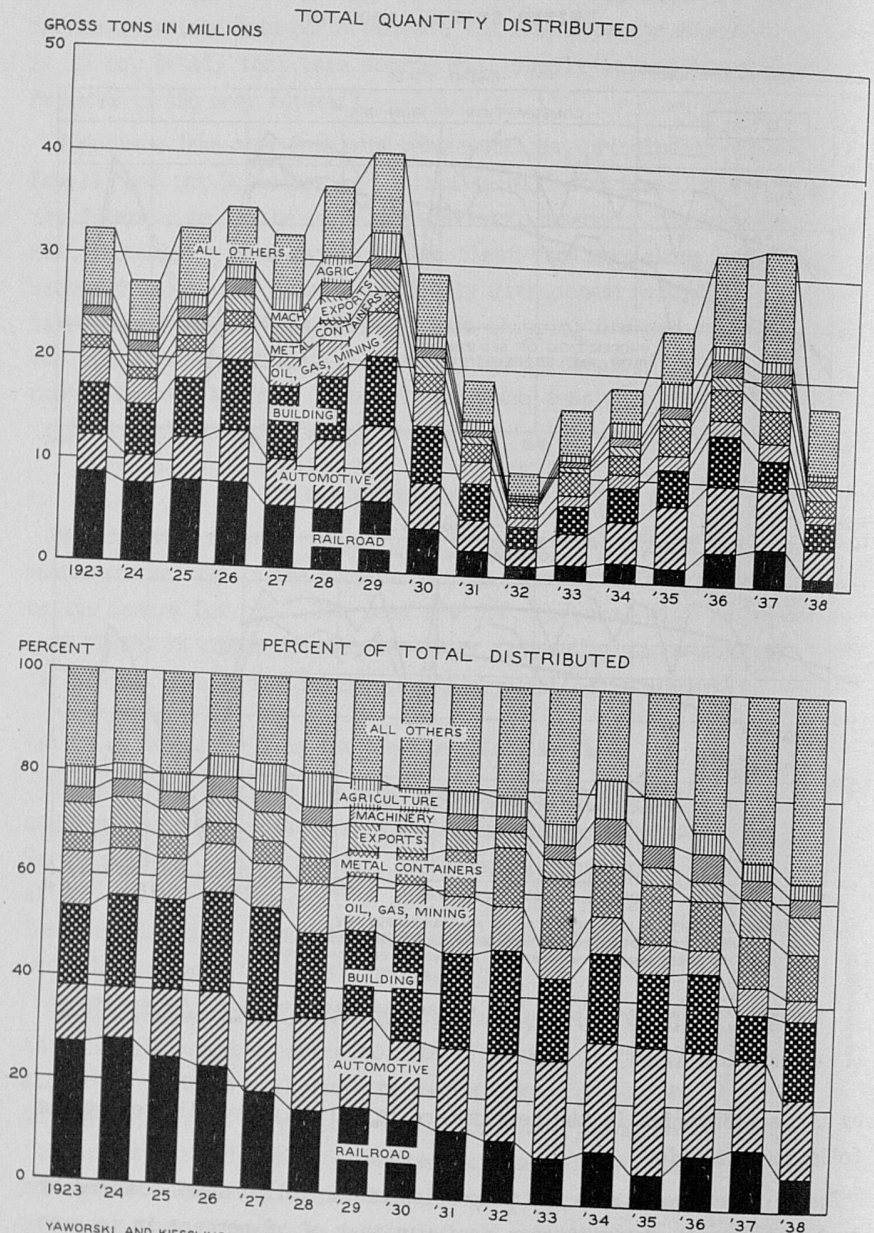
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BASED ON TABLE A-26

by these industries in the near future is unlikely is indicated by the following analysis.

The Railroad Industry.- The proportion of the rolled steel consumed by railroads has declined from a post-war peak of 28 percent in 1924 to about 7 percent in 1938. For several decades up to about 1916 the number of miles of railroad track operated in this country increased to a total of about 260,000 miles. Thereafter railway mileage declined and was about 251,000 miles in 1937. (See figure 50 and table A-26.) The production of iron and steel rails, primarily for replacements, has declined irregularly since about 1906. Fundamentally, the consumption of

Figure 49.- ROLLED-STEEL PRODUCTS DISTRIBUTED TO MAJOR CONSUMING INDUSTRIES, 1923-38



YAWORSKI AND KIESSLING
U.S. BUREAU OF MINES
BASED ON TABLE A-25

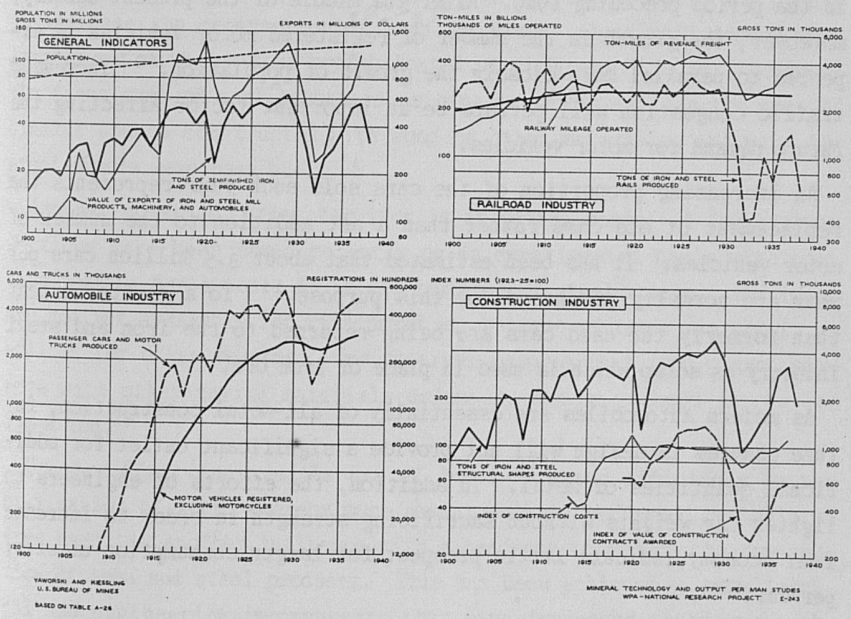
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iron and steel by the railroads now depends upon the amount of railroad traffic. Ton-miles of revenue freight and passenger-train car-miles have increased very little since the World War period and at a slower rate than the population growth.

The prospects are that these trends will continue. One of the major factors depressing the volume of railroad-freight traffic is the virtual cessation in the growth of coal production, since coal represents a large proportion of the total tonnage hauled by railroads.[8] Improvements in fuel efficiency,[9] competition of oil and gas and hydroelectric power, and the general slackening in the growth of production by the coal-consuming industries in this country are among the important rea-

Figure 50.- SALIENT TRENDS AFFECTING IRON CONSUMPTION IN THE UNITED STATES, 1900-38

(Ratio scale)



sons for the slower growth in railroad coal traffic. Other influences that will continue to retard the growth in the volume of railroad-freight traffic are: the reduction of wasteful consumption in industry and more

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[8] For a general statement on the past trend of bituminous-coal production, see Willard E. Hotchkiss, F. G. Tryon, and Others, *Mechanization, Employment, and Output per Man in Bituminous-Coal Mining* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-8, Aug. 1939), I, 1, 5.

[9] For a summary of the progress of fuel efficiency among the major industrial consumers, see Nicholas Yaworski, Vivian Spencer, and Others, *Fuel Efficiency in Cement Manufacture, 1909-1935* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-5, Apr. 1938), ch. I.

efficient use of raw materials; better location of industries in relation to sources of raw materials and markets and the elimination of circuitous hauls; production of more efficient, more durable, and lighter-weight machinery and equipment; and increased competition from motor vehicles and pipe lines. Although railroads will need much iron and steel to replace old equipment, each replacement will release a supply of iron and steel scrap which will compete with iron ore. At present, railroads are the largest source of high-grade steel-making scrap.

The Automobile Industry.- The proportion of the total rolled-steel products used by the automobile industry increased notably in the post-war period. This proportion rose from 11 percent of the total in 1923 to about 25 percent in 1935 and declined thereafter to about 16 percent in 1938. (See figure 49.) It is believed that the growth in the production of motor vehicles in the next 10 years will not be so rapid as in the period preceding 1929. After the middle of the present century, moreover, the growth in the number of registered motor vehicles is expected to parallel more closely the growth of population.[10] Increased traffic congestion will perhaps be an important factor affecting the future demand for motor vehicles.

An increasing proportion of the cars sold each year represents the replacement of old cars rather than a net addition to the number of motor vehicles. It has been estimated that about 3.5 million cars per year are normally purchased for this purpose.[11] To a greater extent than formerly the used cars are being returned to the iron and steel industry as scrap which is used in place of iron ore.

As modern automobiles are essentially of all-metal construction, future changes in design will not provide a significant outlet for additional quantities of metal. In addition, the efforts of engineers to lighten car weights without sacrificing strength in order to increase fuel economy indicate little prospect for larger consumption of steel per car.[12]

The Construction Industry.- The building and construction industry increased its proportionate share of the total consumption of rolled

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[10] See O. E. Kiessling, H. O. Rogers, and Others, *Technology, Employment, and Output per Man in Petroleum and Natural-Gas Production* (WPA National Research Project in cooperation with U. S. Department of the Interior, Bureau of Mines, Report No. E-10, July 1939), pp. 300-1.

[11] A. H. Allen, "Mirrors of Motordom," *Steel*, Vol. 102, No. 1 (Jan. 3, 1938), pp. 221-2. See also C. E. Griffin, *The Life History of Automobiles* (Ann Arbor, Mich.: Univ. of Mich., School of Business Administration, Bureau of Business Research, 1928), p. 23.

[12] Allen, *loc. cit.*

steel from 16 percent in 1923 to a peak of 20 percent in 1932; in 1938 it consumed about 15 percent of the total. For several years the possible revival of the construction industry has been looked upon as a major force for the stimulation of industrial activity generally. Although some revival in building and construction has materialized as the result of more favorable financing terms and of increased expenditures for government construction projects, new construction has not expanded enough to increase the consumption of iron and steel to any large extent. (See figure 50.) One of the principal factors retarding a revival of building is the high cost of construction,[13] and there are no present indications that building costs will be materially reduced in the near future. Even a large expansion in building, of course, would not create a large demand for iron and steel unless these materials were extensively used in the construction. The large potential market for dwelling units for families in the lower income brackets, if developed, would not greatly increase the consumption of iron and steel unless this demand were largely met with low-cost prefabricated steel houses. As yet, however, the first cost of such houses is as high as or higher than the cost of similar houses constructed with wood or other materials, and very few steel houses have been built.[14]

Another possible outlet for iron is in paving roads. A few highway sections have been paved recently on an experimental basis with cast iron costing $50 a ton. As in the instance of steel houses, iron roads are not yet available for widespread use because of their high cost, as well as for other reasons. One observer reports that iron cannot compete with other paving materials unless it can be reduced in cost to $30 a ton.[15]

Greater Efficiency in the Use of Iron.- Greater efficiency in the utilization of iron, whereby more useful work is performed per unit of iron used, is another influence with a tendency to reduce the consumption of iron and steel products. This has been achieved by metallurgical and engineering improvements that have increased their strength, durability, and corrosion resistance.[16] The larger proportion of such

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[13] The index of construction costs, based on costs of lumber, steel, cement, and the rates paid common labor, rose from a depression low of 74.0 in 1932 to 110.7 in 1937. (See table A-26.)

[14] See Charles F. Berry, "California Builds Steel Houses," *The Iron Age*, Vol. 144, No. 10 (Sept. 7, 1939), p. 46; also H. W. Perry, "Knocked-Down Steel Houses," *The Iron Age*, Vol. 143, No. 13 (Mar. 30, 1939), pp. 38-9.

[15] "Future Highways May Be Iron," *Science and Discovery*, Vol. II, No. 4 (Oct. 1939), p. 23.

[16] The improvement of the quality of iron and steel has to some extent broadened the market for them and stimulated their use for a large variety of new products or products previously made of other materials. This development has been [*Con.*]

products in the form of steel rather than of iron has increased their strength or longevity. The recent rapid growth in the use of alloy steels has resulted in a still more effective product.[17] More economical use of iron in iron and steel products has also been achieved by recent improvements in welding, the use of larger one-piece castings that eliminate many bolts, and the steady replacement of iron castings by more durable steel castings. For example, the use of all-welded, 50-ton railroad boxcars, employing high-tensile-strength, low-alloy steel, has recently permitted a reduction in weight of almost 25 percent.[18] Losses due to rust and corrosion are being reduced, moreover, by the better care and preservation of iron and steel products through galvanizing, through tin, chromium, and other plating, and by the more liberal use of paint.

There have also been economies achieved at iron and steel plants. Somewhat less iron ore is required in the manufacture of iron and steel because losses of iron in slag and blast-furnace flue dust have been reduced. It has been estimated that the loss of iron in the iron and steel industry in the last 30 years has declined from about 15 percent of the total iron in iron-bearing materials consumed at the turn of the century to about 10 percent in the last few years.[19]

The Outlook for Exports.- The possibility of changes in the production of iron and steel for export is another factor that must be taken into consideration in appraising future demand prospects. Since 1920 our exports have not maintained their former rate of increase, have fluctuated widely, and at times have slumped sharply. The export market has been extremely unstable in the past two decades and its future is uncertain. In considering data on exports (and imports), it should be

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[16] [*Con.*] evident for some time and accounts in part for the relative increase in the consumption of steel for the "all other" uses indicated in fig. 49. Despite this trend, however, the growth in the production of iron and steel in the post-war period has slackened. A large proportion of the improved iron and steel products are used to replace heavier or less durable machinery and equipment already made of iron or steel, and this tends ultimately to reduce the demand for iron and steel.

[17] The production of steel classed as alloy steel by the American Iron and Steel Institute has increased from about 2 percent of the total steel in 1910 to over 6 percent in the last decade. See Edwin F. Cone, "Trends in Production of American Alloy Steels and of Electric Steels," *Metals and Alloys*, Vol. 8, No. 7 (July 1937), p. 191. In addition to this there has been an increase in the production of steels with comparatively small additional alloys that are not classed as alloy steels, but are considerably stronger than ordinary steel. For a further discussion of trends in the development of stronger and more durable ferrous metals, see C. C. Furnas, "Metallurgy," *Technological Trends and National Policy* (National Resources Committee, June 1937), pp. 329-66.

[18] See *Steel*, Vol. 102, No. 1 (Jan. 3, 1938), pp. 204-6.

Estimated research expenditures per ton of finished steel by steel companies increased from 21 cents in 1929 to about 55 cents in 1938. Much of this effort was directed toward increasing the strength and durability of ferrous metals. See George Perazich and Philip M. Field, *Industrial Research and Changing Technology* (WPA National Research Project, Report No. M-4, Jan. 1940), pp. 24-6.

[19] See testimony by Stewart M. Marshall for the defendant in *State of Minnesota* v. *Oliver Iron Mining Co., et al.* (1935), vol. 2, pp. 384-7.

noted that iron and steel products classified as such, and for which specific quantities are recorded, do not present an inclusive picture. To these must be added, as shown in figure 50, such manufactured goods as machinery and automobiles that also embody large quantities of iron and steel.

The current war confuses the immediate outlook for iron and steel exports. It is entirely possible, for example, that the movement of armament steels and related products to belligerents may be increased. Whether the volume of this business would be sufficient to more than offset losses suffered through trade channels that have been disrupted by the war cannot be determined. Much depends also on whether the war will be long and costly. If it is, a temporary stimulation of exports may be expected to be followed by almost complete disappearance of many export markets as bankrupt or near-bankrupt nations are confronted with their problems of post-war reconstruction.

The prospect for iron and steel exports under peacetime conditions, however, is fairly clear and little increase can be expected. Over the past two decades other countries have sought to become self-sufficient with respect to the basic industries, especially those essential in time of war. Their iron- and steel-producing capacities have been increased more rapidly than those of the United States and this is reflected in a more rapid relative growth of iron and steel production. For example, while the quantity of pig iron produced in the United States increased 36 percent between 1922 and 1937, pig-iron production in all other countries increased 122 percent; and while the production of steel in the United States rose 44 percent during this period, that of all other countries increased 148 percent.[20] It seems reasonably certain, therefore, that greatly expanded exports of iron and steel from this country cannot be expected under peacetime conditions in the near future.

Increased Use of Ferrous Scrap

The demand for iron and steel products is not a precise indicator of the demand for iron ore. This is because the quantity of newly mined ore required to make a ton of pig iron or steel has been declining because of the increased use of ferrous scrap. This trend is shown in figure 48 by the more rapid growth in the production of iron and steel than in the consumption of iron ore. From 1900 to 1909 about 1.7 tons of iron ore were consumed for each ton of steel and non-steel-making

[20] Derived from data for the United States as presented in table A-2 and from data for other countries as given in *Annual Statistical Report of the American Iron and Steel Institute for 1937* (New York: American Iron and Steel Institute, 1938), pp. 89-94.

pig iron produced in the United States. This ratio has declined until in the period from 1930 through 1938 about 1.0 ton of iron ore was required for each ton of iron or steel.[21]

Table 21.- TONS OF IRON ORE CONSUMED PER TON OF STEEL AND NON-STEEL-MAKING PIG IRON PRODUCED IN THE UNITED STATES, 1900-38[a]

Year	Tons	Year	Tons
1900-04	1.71	1920-24	1.28
1905-09	1.70	1925-29	1.23
1910-14	1.55	1930-34	1.04
1915-19	1.41	1935-38	1.04

[a]Based on table A-28.

The proportionate consumption of both home (plant) and purchased scrap in steel making in the United States has increased since 1909. About half of the total quantity of scrap utilized is purchased scrap. It has been estimated that about two-thirds of the tonnage of iron and steel products ultimately returns to the furnaces as scrap and that the remaining one-third is dissipated through rust or corrosion or is permanently lost in some other manner. The growth in the use of purchased scrap is especially significant in curtailing the consumption of iron ore. Home or plant scrap is merely recycled iron or steel, and the large supply of this material shown by surveys is partly due to changed methods of iron and steel fabrication.

The quantity of purchased scrap used for steel making, which excludes the consumption of scrap at a large number of iron foundries, increased from about 17 percent of the total iron in iron-bearing materials consumed in 1909 to a peak of 27 percent in 1935. The average for the 4 years 1935-38 was about 25 percent, as domestic consumers had to compete against an abnormally strong export demand.[22] (See figure 51.) Evidence of the upward trend in the consumption of purchased scrap has also been presented by other observers.[23]

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[21]It should be noted also that the ratio declined despite an increase in the relative amount of steel produced (see fig. 3). Steel has a higher iron content than pig iron. Furthermore, the tonnage of iron ore used in making the compilations has not been adjusted for a slight long-time decline in its iron content. (See table A-4.) On the other hand, the increased efficiency in extracting the iron content from the ore in the smelting process is also reflected in the ratio.

[22]Annual exports of ferrous scrap averaged about 300,000 gross tons during 1925-29. They rose to a peak of 4,100,000 gross tons in 1937 and were about 3,000,000 tons in 1938. See James S. Earle, "Consumption of Ferrous Scrap and Pig Iron Lower in 1938," *Mineral Market Reports* (U. S. Dept. Int., Bur. Mines, No. M. M. S. 750, mimeo., June 12, 1939), p. 5.

Footnote 23 appears on following page.

The average annual tonnage of purchased scrap used in steel making alone for the years 1935-38 had an iron content equivalent to about 21 million tons of iron ore. For the same period the average annual quantity of purchased scrap consumed in steel furnaces, blast furnaces, and iron foundries together had an iron content equivalent to about 28.9 million tons of iron ore.[24] That the use of purchased scrap represents a major inroad into the iron-ore market is indicated by the fact that the average annual consumption of iron ore during the same years amounted to 45.4 million tons.

A continuation of the upward trend in the consumption of purchased scrap is anticipated in the next decade. A main reason why an increased supply of ferrous scrap is assured is the maturing nature of our industrial economy. The large amount of iron and steel products used in this country, weighing perhaps as much as a billion tons, is growing slowly each year and represents a large potential future source of scrap. Each year's accretion to the total quantity of iron and steel articles, moreover, is more durable and corrosion-resistant.

Not only is the total stock of iron and steel products large, increasing, and better preserved, but a larger proportion of the current production of these products is for the purpose of replacement of old, worn-out, or obsolete equipment. Each replacement creates an additional supply of scrap. This is particularly true of the railroad industry, the largest source of heavy melting steel scrap. New rails, for example, are now seldom used for the building of new lines but most frequently replace old rails which are scrapped.

A development that stimulated the increased use of scrap was the shift to the open-hearth process of steel making. Prior to 1908 most domestic steel was made by the Bessemer process, in which air is blown through a charge of liquid pig iron, and relatively little scrap can be used. One of the important reasons for the rise of the open-hearth process was that it made possible the use of large accumulations of scrap. About 90 percent of the present domestic steel production is open-hearth. The usual open-hearth furnace charge is about one-half scrap and one-half pig iron, but the process is sufficiently flexible to permit the use of a much larger proportion of scrap. Some steel plants far removed from

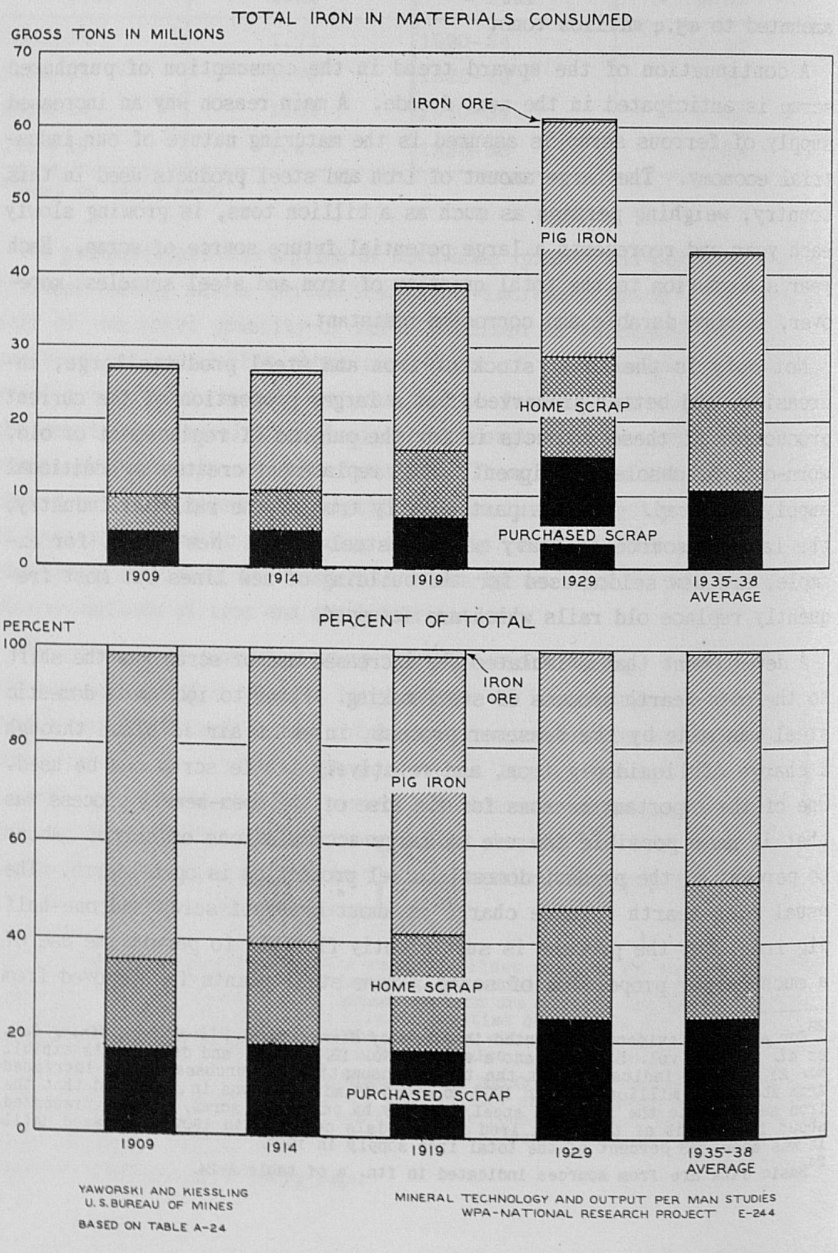
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[23] For example, evidence presented in *State of Minnesota* v. *Oliver Iron Mining Co., et al.* (1935), vol. 5, defendant's exhibit No. 19, p. 328, and defendant's exhibit No. 21, p. 330 indicated that the total consumption of purchased scrap increased from about 6.5 million tons in 1907 to about 17 million tons in 1927, and that the iron supplied to the iron and steel industry by purchased scrap, which represented about 18 percent of the total iron in materials consumed in 1907, increased until it was about 33 percent of the total iron supply in 1927.

[24] Basic data are from sources indicated in ftn. a of table A-24.

the source of iron ore have actually operated on a 100-percent scrap charge. Although the possibility of further extension of the open-hearth process of steel making is definitely limited, the steel industry is capable of consuming still larger quantities of scrap without changing existing plant facilities.

Figure 51.- IRON IN MATERIALS CONSUMED IN STEEL MAKING IN THE UNITED STATES, 1909-38



YAWORSKI AND KIESSLING
U.S. BUREAU OF MINES
BASED ON TABLE A-24

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The demand for better-quality iron and steel has also increased the demand for high-grade steel scrap both for charging the open-hearth steel furnaces and for use in the cupola furnaces of iron foundries to improve the iron and increase its tensile strength.

Better facilities are available for gathering scrap. The development of acetylene torches for reducing large pieces of scrap into smaller and more easily handled segments, the development of the electromagnetic method for economical loading and unloading of scrap, the use of powerful presses or scrap-baling machines, and the development of a sizable industrial organization for the systematic collection, grading, and preparation of scrap are all factors that have increased the supply of scrap and tend to assure its continuation.

Influences retarding the consumption of scrap in the domestic iron and steel industry are of a minor or temporary character. High scrap prices in recent years due to the vigorous foreign demand for scrap have given iron ore a temporary competitive advantage in the domestic market, which may continue as long as the arming nations purchase scrap at premium prices. Although growth in the production of alloy steels reduces the loss of metal through corrosion, the return of alloy-steel scrap creates some additional metallurgical problems. An increase in the proportionate production of lightweight iron and steel products, such as small metal containers, also reduces somewhat the available supply of scrap suitable for use in steel furnaces. In general, however, the factors making for increased scrap consumption outweigh counteracting influences, and recent trends in the consumption of iron and steel scrap are expected to continue for at least the next decade.

Outlook for Ore Production in the Decade 1938-47

It is not possible, of course, to estimate with precision the probable effects of all factors that will influence demand even for so short a period as a decade. It is also clear that the exact level of future demand will be governed by a number of important variables. Nevertheless, if it is assumed that trends already apparent will be the important determinants of future output, then a reasonable answer regarding the probable short-time course of production can be given.

As already noted, important recent influences depressing the iron-ore market have been a slower rate of increase in iron and steel production and a greater use of ferrous scrap. These trends have reflected basic factors such as a declining rate of population increase, a slowing down

of industrial expansion (particularly in the heavy industries), instability in the export trade, and greater economy in the use of iron.[25]

Assuming a continuation of the basic influences in the iron-ore market during the past two decades, the average rate of iron-ore production in the near future probably will not change greatly from the average for a recent and representative period. Demand over the 9 years 1922-30 is selected as representative of future requirements because this period includes years of both high and low output (see figure 9 on page 32) and because it was less affected than any other recent period by the abnormal conditions of war and depression.[26] Average annual output for the 9 years was 62 million gross tons of merchantable ore and it is believed that the average annual production for the decade 1938-47 will be approximately the same.

It is to be expected that output in most of the individual years will vary rather widely from the estimated probable annual average for the 10 years, since production in any single year will depend upon the prevailing level of general business and upon temporary changes in producers' and consumers' stocks and in exports. The record for the 3 years 1937-39 illustrates the year-to-year fluctuations that may be expected in the future. With high business activity in 1937, ore production was 72 million tons; only 61 million tons were actually used in this country or exported during that year, while stocks on hand at Lake Erie docks and at blast furnaces increased. When industrial activity slumped in 1938, iron-ore production declined to 28 million tons; the quantity of domestic ore used and exported, however, amounted to 31 million tons, for an increase of about 2 million tons in stocks at mines was more than offset by a decline in stocks at Lake Erie docks and furnaces. Preliminary figures for 1939 indicate a mine output of 52 million tons, although requirements for consumption and exports of domestic ore were about 55 million tons.[27] Similar yearly fluctuations in the future are certain.

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[25] Some observers may feel that the authors have not given enough weight to the potentiality that the domestic armament program may greatly increase demand or that a rapid expansion in the manufacture of plastics may further depress the market for iron. Such developments, however, represent counterbalancing influences and it is believed that (barring domestic armament production on a much greater scale than occurred during 1939) they would be overshadowed by more important factors.

[26] A computed trend line for the average annual iron-ore production in the United States during 1915-38 shows a downward slope because of the unusually high production during the World War at the beginning of the period and the unusually low production of the years 1930-38 at the end of the period.

[27] For preliminary data on production and shipments during 1939, see Robert H. Ridgway and H. W. Davis, "Iron Ore Industry in 1939 - Advance Summary," *Mineral Market Reports* (U. S. Dept. Int., Bur. Mines, No. M. M. S. 795, mimeo., Jan. 17, 1940). For data on stocks at furnaces and Lake Erie docks, see *Lake Superior Iron Ores: 1938* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), p. 330; also *Tons Consumed, Tons on Hand, Blast Furnace Operations, Revised Statement, December 1939* (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., mimeo., Jan. 22, 1940), p. 1.

FUTURE DEMAND FOR MANPOWER

The employment a given production of iron ore will provide is governed by how much labor will be required to produce a unit of product. Thus the probable course of output per man is a fundamental factor influencing future employment opportunities in iron-ore mining. The trend of output per man, in turn, will depend largely upon how rapidly further technologic changes and improvements will take place and how successfully they will overcome physical difficulties that result from the depletion of the highest-grade and most accessible ore deposits. It will also depend upon probable changes in the character of the operating units supplying the bulk of the output, such as a shift to or away from large, efficient mines using open-pit methods.

Probable Trend of Output per Man

Enough material has been presented in earlier chapters to suggest many potential technological developments that will continue to increase output per man. One significant fact is that a large number of new techniques are being adopted at the present time. The iron-mining industry is alive to new improvements and this alertness presages further technical advances. Although some of the iron mines will experience greater physical difficulties in the next decade and output per man may not increase at a few of them, general progress in the industry will increase the average productivity of labor. As in the immediate past, increased use of electric power, improved drilling, loading, haulage, and other practices, and the more widespread introduction of such modern methods as the use of trucks, tractors, and belt conveyors will continue to raise worker output.

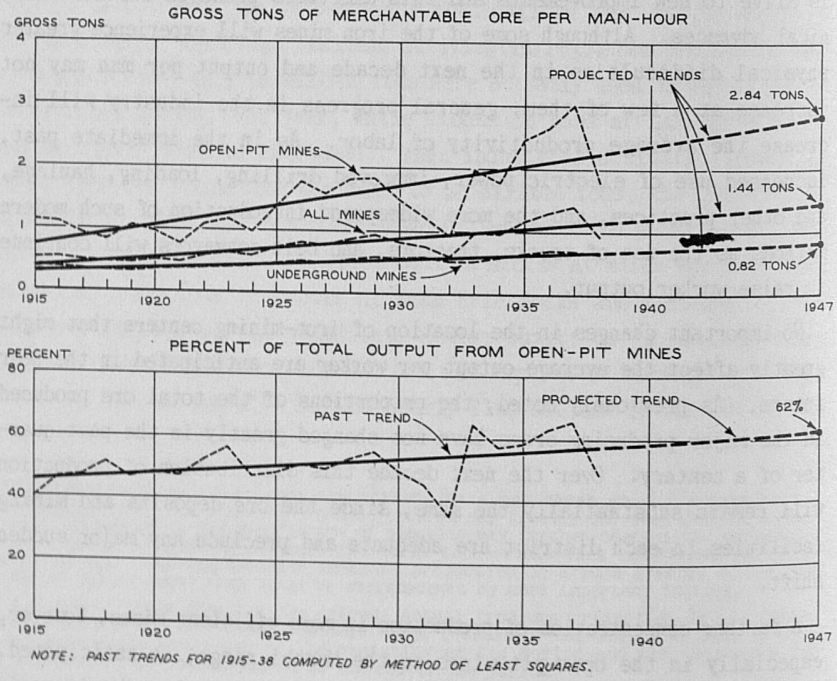
No important changes in the location of iron-mining centers that might greatly affect the average output per worker are anticipated in the near future. As previously noted, the proportions of the total ore produced in the major producing areas have not changed greatly in the past quarter of a century. Over the next decade this distribution of production will remain substantially the same, since the ore deposits and mining facilities in each district are adequate and preclude any major sudden shift.

A further concentration of production in more efficient mines, however, especially in the open-pit mines on the Mesabi range, is anticipated. The steady growth of open-pit mining, noted in preceding chapters, is expected to continue during the next decade. Improved techniques of mining and beneficiation are continually extending the economic limits of open-pit mining. The existing large ore deposits available for this

method of mining on the Mesabi range are sufficient for several decades. By 1947 it is anticipated that about 38 million tons of ore - or about 62 percent of the estimated average yearly output - will be produced by the more productive open-pit methods, and about 24 million tons by underground mines.

Assuming that the average annual increase in labor productivity that prevailed during 1915-38 will continue, by 1947 the average output per man-hour at open-pit mines will be about 2.84 gross tons and at underground operations about 0.82 gross ton. (See figure 52.) The average for all mines in the United States will reflect, as in the past, not only the increase in output per man in each of the two branches of mining, but also the increase in the proportion of the total output that will be mined by open-pit methods. It is estimated that by 1947 the average output per man-hour at all mines will be about 1.44 gross tons.[28]

Figure 52.- OUTPUT PER MAN-HOUR IN OPEN-PIT AND UNDERGROUND IRON MINES AND PERCENT OF TOTAL OUTPUT FROM OPEN-PIT MINES IN THE UNITED STATES, PAST TRENDS 1915-38, AND PROJECTED TRENDS 1938-47



NOTE: PAST TRENDS FOR 1915-38 COMPUTED BY METHOD OF LEAST SQUARES.

YAWORSKI AND KIESSLING
U. S. BUREAU OF MINES

MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES
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BASED ON TABLE A-6

Footnote 28 appears on following page.

Table 22.- AVERAGE ANNUAL EMPLOYMENT DURING 1922-30, 1929, AND 1937 IN IRON MINING IN THE UNITED STATES, AND ESTIMATED FUTURE LABOR REQUIREMENTS IN 1947[a]

(Excludes operations producing ore containing 5 percent or more manganese)

Item	1922-30 average	1929	1937	1947 estimated trend value
Production of merchantable ore (gross tons)	61,739,217	73,027,720	72,093,548	62,000,000[b]
Open-pit mines	31,938,911	40,653,836	47,451,101	38,000,000[c]
Underground mines	29,800,306	32,373,884	24,642,447	24,000,000[c]
Domestic iron ore consumed and exported[d] (gross tons)	61,703,897	72,916,204	60,925,988	62,000,000[c]
Output per man-hour (gross tons)	0.740	0.947	1.402	1.44[e]
Open-pit mines	1.423	1.837	3.005	2.84[e]
Underground mines	0.488	0.589	0.692	0.82[e]
Total man-hours	83,446,678	77,111,086	51,416,193	43,000,000[f]
Open-pit mines	22,439,999	22,133,582	15,788,218	14,000,000[f]
Underground mines	61,006,679	54,977,504	35,627,975	29,000,000[f]
Average length of shift (hours)	9.0	8.9	8.0	8.0[g]
Open-pit mines	9.6	9.7	8.1	8.0[g]
Underground mines	8.7	8.7	8.0	8.0[g]
Total man-shifts	9,319,663	8,638,234	6,396,831	5,375,000[h]
Open-pit mines	2,336,417	2,289,132	1,944,637	1,750,000[h]
Underground mines	6,983,246	6,349,102	4,452,194	3,625,000[h]
Average number of shifts per man per year	268	281	247	246[i]
Open-pit mines	239	269	212	212[j]
Underground mines	280	285	266	266[j]
Average number of employees	34,745	30,763	25,945	21,883
Open-pit mines	9,770	8,521	9,185	8,255[k]
Underground mines	24,975	22,242	16,760	13,628[k]

[a] Basic data are from reports of iron-mining companies to the U. S. Bureau of Mines.

[b] Estimated to be approximately equal to the annual average for 1922-30.

[c] The apportionment of the 1947 estimated production trend between open-pit and underground mines is based on the assumption that the open-pit production will increase to about 62 percent of the total.

[d] Derived by subtracting from the total quantity of iron and manganiferous ore consumed in the United States (see table A-26) the estimated amount of manganiferous ore consumed and the excess of iron-ore imports over exports.

[e] Derived by assuming the same average annual increase after 1938 as during the period 1915-38.

[f] Derived by dividing the estimated trend of production in 1947 by the estimated trend of output per man-hour.

[g] Assumed to be approximately equal to the average length of shift in 1937.

[h] Derived by dividing the estimated number of man-hours that will be required in 1947 by 8.

[i] Derived by dividing the estimated number of man-shifts by the estimated number of employees. The average reflects an anticipated relative increase in open-pit mining.

[j] Assumed to be the same as in 1937.

[k] Derived from the total number of man-shifts by assuming the same average number of shifts per man as in 1937.

Future Employment Levels

By using the anticipated level of iron-ore production and the estimated trend of output per man-hour it is possible to estimate the corresponding total man-hour requirements. The production of about 62 million gross tons at the average rate of 1.44 tons per man-hour will on these

[28] In the event that iron-ore prices are reduced substantially below their present level, e. g., as a result of the new policy of the U. S. Steel Corporation to sell ore on the open market, as considered in the preceding chapter, the trend toward open-pit mining may be further accelerated and average output per man-hour may reach a higher level than that estimated.

It should be noted that the 1.44 gross tons per man-hour represents an estimated trend value. As in the past, actual productivity in a given year will be strongly influenced by short-term changes in the volume of production and in the relative amount of development work performed, especially the stripping of overburden at open-pit mines.

assumptions require approximately 43 million man-hours in 1947. This figure may be compared with an average of 83.4 million man-hours during 1922-30, when the average annual production was also 62 million tons, and with 51.4 million man-hours in 1937, when the high output of 72 million tons was achieved.

The number of men required, as distinguished from total man-hours, will depend on the length of shift as well as the annual average number of shifts worked per man. Assuming that the prevailing 8-hour shift will remain standard and that the average number of shifts worked per man will be approximately the same as in 1937 - namely, 212 at open-pit mines and 266 at underground mines - the number of wage earners who will obtain their livelihood from the iron-mining industry in 1947 will be about 22,000, comprising 8,000 at open-pit mines and 14,000 at underground operations. (See table 22.)

A forecast of general levels of employment for more than a decade becomes difficult and questionable due to great uncertainties regarding future markets and major technical innovations. Nevertheless, significant clues to some of the important factors that will influence employment in the more distant future are already apparent. The long-time prospect in iron-ore mining, for example, is one of growing physical difficulties of operation as the high-grade and easily accessible ore is depleted. Information regarding domestic iron-ore deposits is more complete than knowledge regarding the reserves of any other mineral except coal.[29] This is particularly true of the deposits near the surface, where the labor requirements for mining are relatively low. The possibility of new major discoveries that would materially change this outlook is slight. With increased depth at iron mines and greater necessity for the beneficiation of lean ores, labor requirements per ton of merchantable ore may no longer decline and it is likely that they may even increase. Over a long-time view, factors making for greater employment seem to outweigh those making for less.

[29] Leith and Liddell, *op. cit.*, p. 5.

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Table A-1.- PRODUCTION OF IRON ORE, BY STATE, 1880-1937[a]

(Thousands of gross tons; after 1905, exclusive of ore containing 5 percent or more manganese)

Year	Minnesota		Michigan and Wisconsin		Alabama		New York, New Jersey, and Pennsylvania		All other States		United States total
	Tons	Percent of total	Tons	Percent of total	Tons	Percent of total	Tons	Percent of total	Tons	Percent of total	(tons)
1880	-	-	1,678	23.6	171	2.4	3,754	52.7	1,517	21.3	7,120
1889	865	6.0	6,693	46.1	1,570	10.8	3,224	22.2	2,166	14.9	14,518
1890	892	5.6	8,091	50.5	1,898	11.8	3,111	19.4	2,044	12.7	16,036
1891	945	6.5	6,716	46.0	1,987	13.6	2,816	19.3	2,127	14.6	14,591
1892	1,255	7.7	8,334	51.1	2,312	14.2	2,440	15.0	1,956	12.0	16,297
1893	1,500	12.9	5,107	44.1	1,742	15.0	1,588	13.7	1,651	14.2	11,588
1894	2,968	25.0	4,767	40.1	1,493	12.6	1,052	8.8	1,600	13.5	11,880
1895	3,866	24.2	6,461	40.5	2,199	13.8	1,489	9.3	1,943	12.2	15,958
1896	4,284	26.8	6,314	39.4	2,042	12.8	1,398	8.7	1,967	12.3	16,005
1897	5,601	32.0	6,641	37.9	2,099	12.0	1,314	7.5	1,863	10.6	17,518
1898	5,964	30.7	7,857	40.4	2,402	12.4	1,228	6.3	1,983	10.2	19,434
1899	8,161	33.1	9,726	39.4	2,663	10.8	1,709	6.9	2,424	9.8	24,683
1900	9,834	35.7	10,673	38.7	2,759	10.0	1,663	6.0	2,624	9.6	27,553
1901	11,110	38.5	10,393	36.0	2,802	9.7	1,863	6.4	2,719	9.4	28,887
1902	15,138	42.7	11,919	33.5	3,574	10.0	1,820	5.1	3,103	8.7	35,554
1903	15,371	43.9	11,275	32.2	3,685	10.5	1,670	4.8	3,018	8.6	35,019
1904	12,729	46.0	7,573	27.4	3,700	13.4	1,739	6.3	1,903	6.9	27,644
1905	21,735	51.1	11,745	27.6	3,783	8.9	2,475	5.8	2,788	6.6	42,526
1906	25,364	53.1	12,671	26.5	3,995	8.4	2,534	5.3	3,186	6.7	47,750
1907	28,970	56.1	12,669	24.5	4,039	7.8	2,762	5.3	3,281	6.3	51,721
1908	18,652	51.8	9,573	26.6	3,734	10.4	1,535	4.3	2,489	6.9	35,983
1909	29,128	56.3	12,968	25.1	4,687	9.1	2,212	4.3	2,723	5.2	51,718
1910	31,967	56.0	14,454	25.3	4,801	8.4	2,549	4.5	3,244	5.8	57,015
1911	24,645	56.2	11,028	25.1	3,828	8.7	2,065	4.7	2,311	5.3	43,877
1912	34,432	62.4	12,051	21.8	4,564	8.3	2,099	3.8	2,004	3.7	55,150
1913	38,659	62.4	13,859	22.4	5,216	8.4	2,274	3.7	1,972	3.2	61,980
1914	21,947	53.0	11,683	28.2	4,839	11.7	1,542	3.7	1,429	3.4	41,440
1915	33,465	60.3	13,610	24.5	5,309	9.5	1,777	3.2	1,365	2.5	55,526
1916	44,585	59.3	19,376	25.8	6,748	9.0	2,395	3.2	2,064	2.7	75,168
1917	44,595	59.2	19,071	25.3	7,038	9.3	2,341	3.1	2,244	3.1	75,289
1918	41,954	60.2	17,988	25.8	5,755	8.3	1,852	2.7	2,109	3.0	69,658
1919	36,001	59.1	16,526	27.1	5,053	8.3	1,902	3.1	1,483	2.4	60,965
1920	39,453	58.4	18,492	27.3	5,894	8.7	2,086	3.1	1,679	2.5	67,604
1921	17,811	60.4	7,540	25.6	2,876	9.7	676	2.3	588	2.0	29,491
1922	28,769	61.0	11,031	23.4	5,235	11.1	1,315	2.8	779	1.7	47,129
1923	44,348	64.0	15,045	21.7	6,783	9.8	1,843	2.6	1,332	1.9	69,351
1924	31,902	58.8	13,041	24.0	6,994	12.9	1,128	2.1	1,202	2.2	54,267
1925	36,856	59.5	15,308	24.7	7,093	11.5	1,301	2.1	1,350	2.2	61,908
1926	40,702	60.2	16,571	24.5	6,848	10.1	1,944	2.9	1,558	2.3	67,623
1927	35,461	57.4	16,166	26.2	6,445	10.4	2,244	3.6	1,425	2.4	61,741
1928	37,564	60.4	14,962	24.1	6,308	10.1	1,987	3.2	1,376	2.2	62,197
1929	45,761	62.7	17,065	23.4	6,453	8.8	2,195	3.0	1,554	2.1	73,028
1930	34,518	59.1	14,866	25.5	5,738	9.8	2,249	3.8	1,038	1.8	58,409
1931	17,445	56.0	8,432	27.1	3,615	11.6	937	3.0	703	2.3	31,132
1932	5,154	52.3	2,985	30.4	1,375	14.0	165	1.6	168	1.7	9,847
1933	11,949	68.1	2,662	15.2	2,133	12.2	396	2.2	413	2.3	17,553
1934	15,390	62.6	5,641	22.9	2,344	9.6	909	3.7	304	1.2	24,588
1935	19,375	63.5	5,994	19.6	3,278	10.7	1,349	4.4	544	1.8	30,540
1936	31,634	64.8	10,147	20.8	4,180	8.6	2,070	4.2	758	1.6	48,789
1937	48,417	67.1	13,241	18.4	6,308	8.7	3,145	4.4	983	1.4	72,094

[a]Data represent merchantable ore produced. No record is available for iron ore produced in the years 1881-88. Data for 1880-1908 and 1910-29 from Fifteenth Census of the United States: 1930, "Mines and Quarries: 1929" (U. S. Dept. Com., Bur. Census, 1933), p. 316; for 1909 from Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (1913), p. 242; for 1930-31 from Mineral Resources of the United States, 1931 (U. S. Dept. Com., Bur. Mines, 1934), pt. I, p. 120; for 1932-33 from Minerals Yearbook, 1934 (U. S. Dept. Int., Bur. Mines, 1934), p. 341; for 1934 from same, 1936 (1936), p. 376; for 1935-36 from same, 1937 (1937), p. 582; for 1937 from same, 1938 (1938), p. 489.

Table A-2.- PRODUCTION OF IRON ORE, PIG IRON, AND STEEL IN THE UNITED STATES, 1860-1937

(Thousands of gross tons)

Year	Iron ore[a]	Pig iron[b] (Including ferro-alloys)	Steel[c]	Year	Iron ore[a]	Pig iron[b] (Including ferro-alloys)	Steel[c]
1860	2,873	821	0	1900	27,553	13,789	10,188
1861	n.a.	653	0	1901	28,887	15,878	13,474
1862	n.a.	703	0	1902	35,554	17,821	14,947
1863	n.a.	846	8	1903	35,019	18,009	14,535
1864	n.a.	1,014	9	1904	27,644	16,497	13,860
1865	n.a.	832	14	1905	42,526	22,992	20,024
1866	n.a.	1,206	17	1906	47,750	25,307	23,398
1867	n.a.	1,305	20	1907	51,721	25,781	23,363
1868	n.a.	1,431	27	1908	35,983	15,936	14,023
1869	n.a.	1,711	31	1909	51,718	25,795	23,955
1870	3,932	1,665	67	1910	57,015	27,304	26,095
1871	n.a.	1,707	73	1911	43,877	23,650	23,676
1872	n.a.	2,549	143	1912	55,150	29,727	31,251
1873	n.a.	2,561	199	1913	61,980	30,966	31,301
1874	n.a.	2,401	216	1914	41,440	23,332	23,513
1875	n.a.	2,024	390	1915	55,526	29,916	32,151
1876	n.a.	1,869	533	1916	75,168	39,435	42,774
1877	n.a.	2,067	570	1917	75,289	38,621	45,061
1878	n.a.	2,301	732	1918	69,658	39,055	44,462
1879	n.a.	2,742	935	1919	60,965	31,015	34,671
1880	7,120	3,835	1,247	1920	67,604	36,926	42,133
1881	n.a.	4,144	1,588	1921	29,491	16,688	19,784
1882	n.a.	4,623	1,737	1922	47,129	27,220	35,603
1883	n.a.	4,596	1,674	1923	69,351	40,361	44,944
1884	n.a.	4,098	1,551	1924	54,267	31,406	37,932
1885	n.a.	4,045	1,712	1925	61,908	36,701	45,394
1886	n.a.	5,683	2,563	1926	67,623	39,373	48,294
1887	n.a.	6,417	3,339	1927	61,741	36,566	44,935
1888	n.a.	6,490	2,899	1928	62,197	38,156	51,544
1889	14,518	7,604	3,386	1929	73,028	42,614	56,433
1890	16,036	9,203	4,277	1930	58,409	31,752	40,699
1891	14,591	8,280	3,904	1931	31,132	18,426	25,946
1892	16,297	9,157	4,928	1932	9,847	8,781	13,681
1893	11,588	7,125	4,020	1933	17,553	13,346	23,232
1894	11,880	6,657	4,412	1934	24,588	16,139	26,418[d]
1895	15,958	9,446	6,115	1935	30,540	21,373	34,439[d]
1896	16,005	8,623	5,282	1936	48,789	31,029	48,442[d]
1897	17,518	9,653	7,157	1937	72,094	37,127	51,277[d]
1898	19,434	11,774	8,933				
1899	24,683	13,621	10,640				

[a]Data for 1860 and 1870 from Special Reports of the Census Office, "Mines and Quarries: 1902" (U. S. Dept. Com. and Labor, Bur. Census, 1905), p. 395; for 1880 and 1889-1937 from table A-1.

[b]Data for 1860-1915 from Annual Statistical Report of the American Iron and Steel Institute for 1915 (New York: American Iron and Steel Institute, 1916), pp. 9-10; for 1916-20 from same, 1920 (1921), p. 3; for 1921-24 from same, 1925 (1926), p. 3; for 1925-37 from same, 1937 (1938), p. 6.

[c]Data for 1860-76 from James M. Swank, History of the Manufacture of Iron in All Ages, and Particularly in the United States for Three Hundred Years, From 1585 to 1885 (Philadelphia, Pa.: James M. Swank, 1884), p. 387; for 1877-83 from Annual Statistical Report of the American Iron and Steel Institute for 1915, p. 23; for 1884-1933 from same, 1937, p. 15; for 1934-36 from Edwin F. Cone, "Trends in Production of American Alloy Steels and of Electric Steels, "Metals and Alloys, Vol. 8, No. 7 (July 1937), p. 193; for 1937, estimated by the authors.

[d]Includes an estimate of the production of steel castings that were not reported to the American Iron and Steel Institute.

n.a. Data not available.

Table A-3.- SUMMARY OF PRINCIPAL CENSUS STATISTICS FOR PRODUCING IRON-ORE MINES IN THE UNITED STATES, 1880-1935[a]

	Item	1880[b]	1889	1902	1909	1919	1929	1935
(1)	Number of mines	805	592	525	483	406	206	199
(2)	Persons engaged, total	31,668[c]	38,227[c]	41,256[cd]	50,191	48,767	30,998	16,240[c]
(3)	Proprietors and firm members	n.a.	n.a.	n.a.	76	41	9	n.a.
(4)	Salaried officers and employees[e]	1,253	1,886[f]	2,405	2,870	2,985	2,473	1,367[e]
(5)	Wage earners (average for the year)[g]	30,415	36,341[f]	38,851[d]	47,245	45,741	28,516	14,873
(6)	Power equipment, total horsepower[h]	28,422[i]	57,976[i]	119,558	346,534	370,869	498,821	n.a.
(7)	Horsepower per wage earner[j]	0.9	1.6	3.1	7.3	8.1	17.5	n.a.
(8)	Principal expenses, total[k]	n.a.	$20,986,149	$33,075,922	$53,049,977	$121,804,323	$77,310,634	$28,615,530[l]
(9)	Salaries[e]		$1,425,991[f]	$2,113,230	$3,389,962	$6,936,660	$6,351,462	$3,020,285[e]
(10)	Wages (net earnings of employees)	$9,538,117	$12,983,160[f]	$21,631,792	$29,731,456	$75,713,459	$40,905,190	$14,623,599
(11)	Per ton of ore produced	n.a.	$0.89	$0.61	$0.57	$1.24	$0.55	$0.47[i]
(12)	Percent of principal expenses	n.a.	61.9	65.1	56.0	62.2	52.9	51.3[i]
(13)	Percent of value of products	n.a.	38.9	32.9	27.1	34.7	20.7	19.1
(14)	Contract work[m]	n.a.	$1,578,010	$425,292	$2,698,842	$1,671,783	$1,553,134	(n)
(15)	Percent of principal expenses	n.a.	7.5	1.3	5.1	1.4	2.0	n.a.
(16)	Percent of value of products	n.a.	4.7	0.6	2.5	0.8	0.8	n.a.
(17)	Supplies and materials[o]	$2,894,011	$4,998,988	$9,005,608[p]	$12,597,428	$27,187,832	$18,561,157	$6,646,666
(18)	Fuel					$8,700,358	$5,332,103	$1,599,010
(19)	Purchased power	-	-	(p)	$4,632,289	$1,594,231	$4,607,488[s]	$2,625,970
(20)	Percent of principal expenses	-	-	-	n.a.	1.3	6.0	9.2
(21)	Royalties and rent of mines	$1,020,429[q]			$6,503,908	$15,174,735	$24,944,936	n.a.
(22)	Taxes	n.a.	$3,795,509		$3,970,355	$30,829,610	n.a.	n.a.
(23)	Miscellaneous expenses[r]	n.a.			$1,753,806	$1,876,765	n.a.	n.a.
(24)	Value of products, total[s]	$20,470,756	$33,351,978	$65,465,321	$109,881,000[t]	$218,217,905	$197,334,548	$76,733,841
	Iron ore[u]							
(25)	Quantity (long tons)	6,307,883	14,518,041	35,567,410	51,947,129	61,173,254	73,963,485	31,008,140
(26)	Value at mine, total	$20,470,756	$33,351,978	$65,465,321	$109,473,000[t]	$217,949,311	$196,085,542	$76,721,428
(27)	Value per ton	$3.25	$2.30	$1.84	$2.11	$3.56	$2.65	$2.47
(28)	Other products[v]	-	-	-	$408,000	$268,594	$1,249,006	$12,413
(29)	Total man-shifts worked by wage earners[w]	7,074,000	8,999,613	11,655,300	n.a.	14,593,350	8,785,573	3,328,059
(30)	Average number of shifts per wage earner[x]	233	248	260[y]	n.a.	280	281	219
	Average earnings per wage earner (approximately)							
(31)	Per man-shift[z]	n.a.	$1.44	$1.85	n.a.	$5.19	$4.66	$4.39
(32)	Per annum[aa]	n.a.	$357.12	$481.00	n.a.	$1,453.20	$1,309.46	$961.41
(33)	Tons per man-shift	0.9	1.6	3.1	n.a.	4.2	8.4	9.3
(34)	Wage earners (average for the year)	30,415	36,341	38,851	52,230[bb]	47,740[bb]	28,516	14,599[bb]
(35)	Above ground	16,431	17,319	16,769[d]	24,889[bb]	19,050[bb]	12,655	n.a.
(36)	Percent of total[cc]	54.0	47.7	40.6	47.7	39.9	44.4	n.a.
(37)	Below ground	13,984	19,022	23,082[d]	27,341[bb]	28,690[bb]	15,861	n.a.

[a]Data are from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886) pp. 64-6, 68; Eleventh Census of the

[k]To preserve comparability the total of principal expenses is made up of the same items

[a]Data are from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), pp. 64-6, 69; Eleventh Census of the United States: 1890, "Report on Mineral Industries" (1892), pp. 4, 16-21; Special Reports of the Census Office, "Mines and Quarries: 1902" (U. S. Dept. Com. and Labor, Bur. Census, 1906), pp. 426, 428, 430; Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), pp. 256-9; Fourteenth Census of the United States: 1920, Vol. XI, "Mines and Quarries: 1919" (1922), pp. 352-3; Fifteenth Census of the United States: 1930, "Mines and Quarries: 1929" (1933), pp. 314, 325; "Iron Ore Industry in 1935," Census of Business: 1935 (U. S. Dept. Com., Bur. Census in cooperation with the Bureau of Mines, newspaper release, mimeo., Jan. 26, 1937); Minerals Yearbook, 1937 (U. S. Dept. Int., Bur. Mines, 1937), p. 874.

[b]Data are for regular establishments only and are exclusive of 1,325 small "irregular" establishments which produced 11 percent of the total output of iron ore.

[c]Exclusive of proprietors and firm members.

[d]Wage earners as reported by the Census for 1902 are not comparable with other years as they represent the number that would have been required at continuous employment of 300 days per year to produce the product of that year. Iron mines do not average 300 days per year; hence the number of employees as reported by the Census was lower than the typical number in periods when mines were in operation.

[e]Includes general officers, superintendents, managers, foremen, technical employees, office forces of clerks and stenographers, and all others on a salary basis. Employees at central administrative offices not connected with mine or plant are also included, except for 1935.

[f]The report of the Census for 1889 included foremen with wage earners. To preserve comparability with other years foremen have been excluded from wage earners in this table and included with salaried employees.

[g]The numbers of employees for 1880 and 1889, though comparable with each other, are not comparable with other years, and the data for 1902, with employment reduced to a full-time basis, are not comparable with any other year. The number of wage earners for 1909, 1919, 1929, and 1935 are comparable with each other but not with preceding years. The incomparability of the numbers of employees is due to differences in the methods of computing the averages by the Census officials. In 1880 and 1889 the number of wage earners represents the number employed during the time the mines were active. For other years, the numbers were obtained by totaling the numbers employed in each month and dividing the sum by 12 - even though some mines may not have operated 12 months. Though the numbers of employees are not comparable for all years, the comparison of the ratios of employees above ground to total employees is sufficiently meaningful.

[h]Data represent rated horsepower of prime movers and electric motors using purchased energy. The horsepower rating of electric motors using energy generated at mines has been excluded to avoid duplication. The prime movers include all types of power equipment, both stationary and mobile.

[i]Data represent horsepower rating of steam boilers. The rated horsepower of steam boilers is higher than that of the steam engines to which the boilers supplied power. In 1880 the rated horsepower of steam engines was about 87 percent of the horsepower of steam boilers. In this respect data for 1880 and 1889 are not comparable with later years. However, data for 1880 and 1889 exclude mobile power equipment which is included in other years.

[j]See footnotes g and h. For more comparable year-to-year data on horsepower per wage earner see table A-10.

[k]To preserve comparability the total of principal expenses is made up of the same items for all years; these include salaries (9), wages (10), contract work (14), supplies and materials (17), fuel (18), and purchased power (19). Note that other items of expense are shown for 1880, 1889, 1902, 1909, and 1919, although they are not included in the total.

[l]Exclusive of salaries paid to employees at central administrative offices not connected with mine or plant.

[m]Includes outlays for work which mining companies sometimes let to contractors who make a specialty of the work in question. A large part of the contract work in iron mining was for stripping overburden at open-pit mines, particularly on the Mesabi range.

[n]Included in other items of principal expenses.

[o]Includes lumber and timber, ties, tools and materials for repairs, rails, frogs, feed for animals, lubricants, explosives, etc.

[p]Exclusive of purchased power which was probably negligible in this year.

[q]Royalties only; excludes rent of mines.

[r]Includes rent of offices, insurance, interest, and sundries. Excludes depreciation losses due to bad debts and a few other similar items.

[s]Sum of items (26) and (28).

[t]As estimated by the Census office for comparability with other years. The figure originally reported in the 1909 Census represented the value of iron ore sold or used rather than the value of iron ore produced.

[u]Represents merchantable ore. Includes ore containing 5 to 35 percent manganese; for this reason iron-ore production as reported by the Bureau of Mines, which excluded manganiferous ore, differs from the figures presented here for the years 1909-35.

[v]Includes miscellaneous secondary products, receipts for services performed for others, and for power sold.

[w]Data as presented in table A-4 plus an estimate for 1902-35 of man-shifts required to produce a small quantity of manganiferous ore. The estimate assumed the same unit labor requirements for the production of manganiferous ore as were required for the production of iron ore proper.

[x]Data from table A-4.

[y]Estimated.

[z]Item (10) divided by item (29).

[aa]Item (31) multiplied by item (30).

[bb]Represents number of wage earners on December 15th or representative day.

[cc]See footnote g. Item (35) divided by item (34).

n.a. Data not available.

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a]

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						Percent of industry on which based[d]
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				
		Gross tons	Iron (natural) contained			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
United States																
1880	n.a.	7,120,562	3,647,692	51.23	35,000	231	n.a.	8,077,000[e]	n.a.	n.a.	n.a.	0.882	n.a.	0.452	n.a.	88.6
1889	n.a.	14,518,041	7,443,400	51.27[f]	36,341	248	n.a.	8,998,064[g]	n.a.	n.a.	n.a.	1.615	n.a.	.827	n.a.	100.0
1902	n.a.	35,554,155	n.a.	n.a.	44,800[h]	260[h]	n.a.	11,650,946[i]	n.a.	n.a.	n.a.	3.052	n.a.	n.a.	n.a.	100.0
1915	60,882,000	55,526,490	n.a.	n.a.	45,385	272	8.9	11,808,476	105,528,377	5.156	0.577	4.702	0.526	n.a.	n.a.	94.9
1916	82,161,000	75,167,672	n.a.	n.a.	57,049	274	9.0	15,636,414	140,753,166	5.254	.584	4.807	.534	n.a.	n.a.	98.2
1917	82,869,000	75,288,851	n.a.	n.a.	60,594	280	9.1	16,969,611	155,585,171	4.885	.540	4.437	.490	n.a.	n.a.	96.1
1918	77,447,000	69,658,278	n.a.	n.a.	55,674	295	9.1	16,302,576	148,605,632	4.751	.521	4.275	.469	n.a.	n.a.	94.4
1919	67,612,000	60,965,418	n.a.	n.a.	51,780	280	9.1	14,477,844	131,067,892	4.670	.516	4.211	.465	n.a.	n.a.	96.9
1920	75,514,000	67,604,465	n.a.	n.a.	50,590	287	9.2	14,538,131	133,452,211	5.194	.566	4.650	.507	n.a.	n.a.	88.4
1921	33,246,000	29,490,978	n.a.	n.a.	32,348	209	9.1	6,749,297	61,146,846	4.926	.544	4.369	.482	n.a.	n.a.	97.8
1922	53,736,000	47,128,527	n.a.	n.a.	35,758	250	8.9	8,954,418	79,458,561	6.001	.676	5.263	.593	n.a.	n.a.	96.9
1923	80,669,623	69,351,442	34,970,461	50.42	41,294	286	9.1	11,797,882	107,551,244	6.838	.750	5.878	.645	2.964	0.325	96.5
1924	61,458,841	54,267,419	27,082,183	49.91	38,765	263	9.0	10,201,678	91,324,498	6.024	.675	5.319	.594	2.655	.297	97.7
1925	70,474,965	61,907,997	31,090,824	50.22	35,757	270	8.9	9,665,877	86,340,684	7.291	.816	6.405	.717	3.217	.360	98.3
1926	75,943,775	67,623,000	34,099,262	50.43	34,399	273	9.0	9,395,358	84,225,524	8.085	.902	7.197	.803	3.629	.405	98.0
1927	69,923,057	61,741,100	30,879,989	50.02	34,755	264	8.9	9,177,979	82,004,761	7.619	.853	6.727	.753	3.365	.377	97.5
1928	70,940,916	62,197,088	31,149,584	50.08	30,238	265	8.9	8,006,647	71,405,651	8.858	.994	7.766	.871	3.889	.436	96.9
1929	83,164,881	73,027,720	36,637,660	50.17	30,763	281	8.9	8,638,234	77,111,086	9.628	1.079	8.454	.947	4.241	.475	97.5
1930	68,551,913	58,408,664	29,365,457	50.28	30,975	259	8.9	8,037,096	71,620,115	8.529	.957	7.267	.816	3.654	.410	99.3
1931	35,563,994	31,131,502	15,624,850	50.19	22,867	201	8.9	4,596,504	40,928,283	7.737	.869	6.775	.761	3.399	.382	99.3
1932	11,181,678	9,846,916	4,948,245	50.25	12,649	145	9.0	1,828,002	16,427,009	6.117	.681	5.387	.599	2.707	.301	97.0
1933	21,225,958	17,555,188	8,777,574	50.01	15,125	140	8.5	2,121,494	17,931,489	10.006	1.184	8.274	.979	4.137	.490	99.5
1934	28,252,926	24,587,616	12,384,257	50.37	16,515	195	8.0	3,186,232	25,478,440	8.867	1.109	7.717	.965	3.887	.486	98.4
1935	35,367,816	30,540,252	15,361,718	50.30	14,987	219	8.0	3,277,995	26,281,693	10.789	1.346	9.317	1.162	4.686	.585	99.9
1936	54,856,497	48,788,745	24,684,271	50.59	20,306	227	8.1	4,617,396	37,246,583	11.880	1.475	10.566	1.310	5.346	.663	99.8
1937	80,906,084	72,093,548	36,410,811	50.50	25,945	247	8.0	6,596,851	51,418,195	12.648	1.574	11.270	1.402	5.692	.708	99.5

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained[j]			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Lake Superior District (Minnesota, Michigan, and Wisconsin)																
1880	1,677,814	1,677,814	996,963	59.42	5,410	273	n.a.	1,476,349[e]	n.a.	1.136	n.a.	1.136	n.a.	0.675	n.a.	100.0
1889	7,558,076	7,558,076	n.a.	n.a.	15,930	267	n.a.	4,257,092[f]	n.a.	1.775	n.a.	1.775	n.a.	n.a.	n.a.	100.0
1902	27,056,861	27,056,861	14,980,000	55.36	n.a.	n.a.	n.a.	7,221,900[i]	n.a.	3.746	n.a.	3.746	n.a.	2.074	n.a.	100.0
1915	48,580,000	47,074,564	24,231,000	51.47	30,842	275	8.7	8,471,209	73,996,157	5.735	0.657	5.557	0.636	2.860	0.327	95.5
1916	66,000,000	63,960,956	32,771,000	51.24	40,279	273	8.8	11,015,425	98,755,647	5.992	.682	5.806	.661	2.975	.339	98.7
1917	65,331,000	63,666,068	32,809,000	51.53	42,067	284	8.8	11,933,493	105,599,604	5.475	.619	5.335	.603	2.749	.311	96.1
1918	62,342,000	59,942,661	30,816,000	51.41	39,535	291	8.9	11,459,109	102,207,759	5.440	.610	5.231	.586	2.689	.302	94.5
1919	55,034,000	52,526,803	27,151,000	51.69	35,695	282	8.8	10,085,086	88,870,381	5.458	.619	5.209	.591	2.693	.306	97.6
1920	60,521,000	57,945,049	30,024,000	51.81	35,622	293	9.0	10,420,410	95,752,647	5.808	.646	5.561	.618	2.881	.320	88.5
1921	26,940,000	25,351,831	13,190,000	52.03	22,928	230	9.0	5,285,559	47,343,951	5.099	.569	4.798	.535	2.496	.279	98.1
1922	42,411,000	39,799,562	20,666,000	51.93	24,496	260	8.7	6,362,946	55,041,540	6.665	.771	6.255	.723	3.248	.375	97.5
1923	63,737,822	59,394,180	30,860,060	51.96	28,756	292	8.8	8,397,782	74,197,870	7.590	.859	7.073	.800	3.675	.416	97.1
1924	47,561,165	44,942,898	23,351,488	51.96	27,651	269	8.7	7,449,720	64,679,800	6.384	.735	6.033	.695	3.135	.361	98.6
1925	55,569,424	52,163,922	27,160,188	52.07	25,472	266	8.6	6,857,245	58,970,445	8.127	.942	7.629	.885	3.972	.461	98.6
1926	60,410,352	57,272,645	29,757,718	51.92	24,483	271	8.6	6,645,795	57,094,412	9.090	1.058	8.618	1.003	4.475	.521	98.0
1927	54,744,797	51,627,355	26,647,001	51.61	24,904	258	8.6	6,424,947	55,268,641	8.521	.991	8.035	.934	4.147	.482	97.2
1928	56,059,514	52,525,581	27,061,570	51.52	20,881	266	8.6	5,562,599	47,996,087	10.078	1.168	9.443	1.094	4.865	.564	96.5
1929	67,609,545	62,825,826	32,294,527	51.40	21,811	286	8.7	6,243,609	54,615,027	10.829	1.238	10.062	1.150	5.172	.591	97.4
1930	54,323,659	49,385,385	25,448,164	51.53	22,301	261	8.8	5,825,736	51,197,616	9.328	1.061	8.480	.965	4.370	.497	99.5
1931	28,188,521	25,877,416	13,407,923	51.81	16,487	207	8.8	3,404,984	30,017,397	8.279	.939	7.600	.862	3.938	.447	99.7
1932	9,160,742	8,159,427	4,267,074	52.42	8,768	183	8.9	1,627,926	12,636,707	6.415	.725	5.700	.644	2.988	.338	96.8
1933	16,608,574	14,611,052	7,571,079	51.82	11,598	150	8.5	1,512,172	12,596,969	10.983	1.320	9.662	1.161	5.007	.602	99.5
1934	22,882,450	21,051,019	10,890,320	51.73	12,006	199	8.0	2,391,091	19,120,480	9.562	1.196	8.796	1.100	4.550	.569	98.5
1935	29,033,951	25,368,637	13,214,540	52.09	10,360	227	8.0	2,547,491	18,826,120	12.368	1.542	10.807	1.348	5.629	.702	100.0
1936	46,060,653	41,781,215	21,610,513	51.72	14,126	230	8.0	3,255,920	26,057,994	14.147	1.768	12.832	1.603	6.637	.829	100.0
1937	67,891,515	61,857,635	31,958,270	51.80	17,856	242	8.0	4,525,450	34,649,040	15.703	1.959	14.261	1.779	7.387	.922	99.7

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained[j]			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained[j] Per shift	Iron (natural) contained[j] Per hour	
	(1)	(2)	Gross tons (3)	Percent (4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Minnesota																
1880	0	0	0	-	0	-	-	0	0	-	-	-	-	-	-	-
1889	864,508	864,508	n.a.	n.a.	1,697	249	n.a.	422,826[e]	n.a.	2.046	n.a.	2.046	n.a.	n.a.	n.a.	100.0
1902	15,137,650	15,137,650	8,601,000	56.82	n.a.	n.a.	n.a.	2,476,800[f]	n.a.	6.112	n.a.	6.112	n.a.	3.473	n.a.	100.0
1915	34,928,000	33,464,660	17,104,000	51.11	15,456	269	8.9	4,149,393	36,987,049	8.417	0.944	8.065	0.905	4.122	0.462	98.0
1916	46,588,000	44,585,422	22,685,000	50.88	19,716	253	9.0	4,991,656	44,939,668	9.333	1.037	8.932	.992	4.545	.505	99.4
1917	46,218,000	44,595,232	22,886,000	51.32	21,330	261	9.2	5,985,121	54,812,506	7.725	.845	7.454	.814	3.825	.418	95.9
1918	44,519,000	41,953,969	21,459,000	51.15	20,275	287	9.2	5,815,021	53,589,583	7.624	.827	7.217	.783	3.692	.400	93.0
1919	58,481,000	56,000,626	28,548,000	51.52	16,815	277	9.0	4,654,999	42,069,798	8.267	.915	7.734	.856	3.985	.441	97.6
1920	42,011,000	39,455,175	20,405,000	51.72	17,089	290	9.4	4,949,098	46,754,603	8.489	.899	7.972	.844	4.125	.436	84.2
1921	19,400,000	17,811,325	9,305,000	52.24	11,832	240	9.3	2,844,485	26,518,263	6.820	.732	6.262	.672	3.271	.351	97.8
1922	31,565,000	28,768,980	14,925,000	51.88	12,722	256	8.9	3,260,449	29,066,103	9.620	1.079	8.824	.990	4.578	.513	97.7
1923	48,681,304	44,548,296	23,115,744	52.12	16,014	282	9.2	4,514,256	41,479,648	10.784	1.174	9.824	1.069	5.121	.557	97.5
1924	34,518,865	31,902,085	16,623,410	52.11	14,660	268	9.0	3,925,174	35,258,049	8.794	.980	8.128	.905	4.235	.472	98.9
1925	40,261,746	36,858,244	19,269,806	52.28	13,306	257	8.9	3,419,637	30,287,987	11.775	1.329	10.777	1.217	5.635	.636	98.7
1926	45,859,322	40,701,613	21,296,041	52.32	12,294	260	8.8	3,196,252	28,146,105	13.716	1.558	12.754	1.446	6.665	.757	98.0
1927	38,578,600	35,461,158	18,413,192	51.92	13,218	259	8.8	3,159,948	27,940,067	12.209	1.381	11.222	1.269	5.827	.659	96.8
1928	41,097,738	37,564,005	19,436,781	51.74	10,741	266	8.9	2,858,999	25,329,502	14.375	1.623	13.139	1.491	6.798	.767	95.7
1929	50,544,577	45,760,858	23,576,324	51.52	11,514	282	9.0	3,250,077	29,328,527	15.552	1.725	14.080	1.560	7.254	.804	97.4
1930	39,458,022	34,517,748	17,795,469	51.55	12,007	251	9.1	3,018,650	27,544,613	13.071	1.433	11.435	1.253	5.895	.646	99.0
1931	19,756,108	17,445,005	9,026,305	51.74	8,375	210	9.1	1,760,152	16,096,418	11.224	1.227	9.911	1.084	5.128	.561	99.6
1932	6,175,606	5,154,291	2,713,988	52.65	3,685	191	9.2	705,304	6,462,204	8.761	.956	7.309	.798	3.849	.420	94.9
1933	13,946,158	11,948,596	6,194,413	51.84	6,549	135	8.4	872,188	7,285,060	15.990	1.915	13.700	1.641	7.102	.851	99.4
1934	17,221,501	15,389,870	7,945,555	51.63	6,717	201	8.0	1,347,498	10,779,945	12.780	1.598	11.421	1.428	5.897	.737	98.0
1935	25,059,957	19,574,523	10,095,485	52.11	5,454	256	8.0	1,263,744	10,319,576	17.947	2.235	15.092	1.877	7.864	.978	100.0
1936	35,913,502	31,634,064	16,335,749	51.64	8,197	215	8.0	1,764,465	14,124,795	20.354	2.543	17.928	2.240	9.258	1.157	100.0
1937	54,650,865	48,418,985	25,096,045	51.85	10,372	235	8.0	2,434,168	19,551,053	22.452	2.798	19.891	2.479	10.310	1.285	99.6

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained[j]			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Michigan and Wisconsin																
1880	1,677,814	1,677,814	996,963	59.42	5,410	273	n.a.	1,476,349[e]	n.a.	1.136	n.a.	1.136	n.a.	0.675	n.a.	100.0
1889	6,693,568	6,693,568	n.a.	n.a.	14,233	269	n.a.	3,834,466[f]	n.a.	1.746	n.a.	1.746	n.a.	n.a.	n.a.	100.0
1902	11,919,211	11,919,211	6,379,000	53.52	n.a.	n.a.	n.a.	4,745,100[i]	n.a.	2.512	n.a.	2.512	n.a.	1.344	n.a.	100.0
1915	13,653,000	13,609,904	7,127,000	52.37	15,406	281	8.6	4,321,816	37,009,108	3.159	0.369	3.149	0.368	1.649	0.193	88.4
1916	19,413,000	19,375,534	10,086,000	52.06	20,563	293	8.6	6,023,769	51,793,959	3.223	.375	3.217	.374	1.674	.195	97.1
1917	19,113,000	19,070,836	9,923,000	52.03	20,737	287	8.5	5,950,372	50,787,298	3.212	.376	3.205	.376	1.668	.195	96.7
1918	18,023,000	17,988,692	9,357,000	52.02	19,060	296	8.6	5,646,088	48,618,176	3.192	.371	3.186	.370	1.657	.192	98.0
1919	16,533,000	16,526,177	8,603,000	52.06	18,880	287	8.6	5,428,087	46,800,583	3.050	.354	3.045	.353	1.586	.184	97.5
1920	18,510,000	18,491,876	9,619,000	52.02	18,533	295	8.6	5,471,312	46,998,044	3.383	.394	3.380	.393	1.758	.205	97.0
1921	7,541,000	7,540,506	3,885,000	51.52	11,096	220	8.5	2,439,074	20,825,688	3.092	.362	3.092	.362	1.593	.187	98.7
1922	11,045,000	11,030,602	5,741,000	52.46	11,764	264	8.4	3,102,497	26,975,437	3.560	.425	3.555	.425	1.850	.221	96.9
1923	15,086,518	15,045,884	7,744,316	51.47	12,742	305	8.4	3,883,546	32,718,222	3.877	.460	3.874	.460	1.994	.237	95.7
1924	13,042,312	13,040,813	6,728,078	51.59	12,991	271	8.4	3,524,546	29,441,751	3.700	.443	3.700	.443	1.909	.229	97.7
1925	15,307,678	15,307,678	7,890,382	51.55	12,166	281	8.4	3,417,408	28,682,458	4.479	.534	4.479	.534	2.309	.275	98.3
1926	16,571,030	16,571,030	8,442,677	50.95	12,189	283	8.4	3,449,541	28,948,307	4.804	.572	4.804	.572	2.447	.292	98.0
1927	16,166,197	16,166,197	8,233,809	50.93	11,686	279	8.4	3,264,999	27,328,574	4.951	.592	4.951	.592	2.522	.301	98.2
1928	14,961,576	14,961,576	7,624,589	50.96	10,140	267	8.4	2,703,600	22,686,785	5.534	.660	5.534	.660	2.820	.336	98.7
1929	17,064,968	17,064,968	8,718,203	51.09	10,297	291	8.4	2,993,532	25,286,700	5.701	.675	5.701	.675	2.912	.345	97.3
1930	14,865,637	14,865,637	7,654,695	51.49	10,294	272	8.4	2,805,106	23,653,003	5.299	.628	5.299	.628	2.729	.324	99.9
1931	8,432,413	8,432,413	4,381,618	51.96	8,112	203	8.5	1,644,832	13,920,979	5.127	.606	5.127	.606	2.664	.315	100.0
1932	2,985,136	2,985,136	1,553,086	52.03	5,085	143	8.5	724,622	6,176,503	4.120	.483	4.120	.483	2.143	.251	100.0
1933	2,662,436	2,662,436	1,376,866	51.71	5,049	127	8.3	639,984	5,303,909	4.160	.502	4.160	.502	2.151	.260	99.9
1934	5,641,149	5,641,149	2,934,765	52.02	5,289	197	8.0	1,043,593	8,340,535	5.406	.676	5.406	.676	2.812	.352	99.7
1935	5,994,014	5,994,014	3,119,057	52.04	4,926	216	8.0	1,063,747	8,506,544	5.635	.705	5.635	.705	2.932	.367	100.0
1936	10,147,151	10,147,151	5,274,764	51.98	5,929	252	8.0	1,491,457	11,933,199	6.804	.850	6.804	.850	3.537	.442	100.0
1937	13,240,650	13,240,650	6,842,225	51.68	7,464	253	8.0	1,889,282	15,117,987	7.008	.876	7.008	.876	3.622	.453	100.0

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained[j,k]			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Michigan																
1880	1,640,814	1,640,814	977,515[l]	59.57	5,350	274	n.a.	1,464,148[e]	n.a.	1.121	n.a.	1.121	n.a.	0.668	n.a.	100.0
1889	5,856,169	5,856,169	n.a.	n.a.	12,496	270	n.a.	3,373,562[f]	n.a.	1.736	n.a.	1.736	n.a.	n.a.	n.a.	100.0
1902	11,135,215	11,135,215	5,957,000	53.50	n.a.	n.a.	n.a.	4,336,800[l]	n.a.	2.568	n.a.	2.568	n.a.	1.374	n.a.	100.0
1915	12,557,000	12,514,516	6,545,000	52.30	14,411	279	8.6	4,025,306	34,637,023	3.120	0.363	3.109	0.361	1.626	0.189	87.8
1916	18,108,000	18,071,016	9,397,000	52.00	19,331	293	8.6	5,656,476	48,855,614	3.201	.371	3.195	.370	1.661	.192	97.4
1917	17,910,000	17,868,601	9,292,000	52.00	19,448	286	8.6	5,571,641	47,757,450	3.214	.375	3.207	.374	1.668	.195	96.6
1918	16,934,000	16,899,341	8,788,000	52.00	17,846	295	8.7	5,272,208	45,627,125	3.212	.371	3.205	.370	1.667	.193	97.8
1919	15,466,000	15,438,930	8,028,000	52.00	17,709	286	8.6	5,065,075	43,752,675	3.053	.353	3.048	.353	1.585	.183	97.6
1920	17,528,000	17,510,742	9,106,000	52.00	17,507	294	8.6	5,157,330	44,486,194	3.399	.394	3.395	.394	1.766	.205	98.8
1921	7,283,000	7,283,492	3,751,000	51.50	10,586	214	8.5	2,267,703	19,372,565	3.212	.376	3.212	.376	1.654	.194	98.7
1922	10,466,000	10,453,578	5,436,000	52.00	10,828	266	8.4	2,883,340	24,114,193	3.630	.434	3.626	.434	1.885	.225	97.0
1923	14,177,024	14,174,468	7,303,914	51.53	12,046	306	8.4	3,683,521	31,024,832	3.849	.457	3.848	.457	1.983	.235	96.7
1924	12,352,254	12,350,755	6,368,914	51.57	12,418	271	8.3	3,365,543	28,084,192	3.670	.440	3.670	.440	1.892	.227	97.7
1925	14,490,529	14,490,529	7,464,302	51.51	11,463	283	8.4	3,241,247	27,177,548	4.471	.533	4.471	.533	2.303	.275	98.2
1926	15,248,254	15,248,254	7,763,697	50.92	11,088	282	8.4	3,121,885	26,199,855	4.884	.582	4.884	.582	2.487	.296	97.8
1927	15,075,079	15,075,079	7,673,923	50.90	10,691	277	8.4	2,964,954	24,798,798	5.084	.608	5.084	.608	2.588	.309	98.1
1928	13,676,984	13,676,984	6,953,363	50.84	9,115	268	8.4	2,440,374	20,394,415	5.604	.671	5.604	.671	2.849	.341	98.6
1929	15,456,397	15,456,397	7,875,299	50.95	9,308	290	8.4	2,696,663	22,717,379	5.732	.680	5.732	.680	2.920	.347	97.0
1930	13,544,277	13,544,277	6,956,301	51.36	9,466	270	8.4	2,556,955	21,558,824	5.293	.628	5.293	.628	2.718	.323	99.9
1931	7,552,581	7,552,581	3,914,557	51.83	7,570	197	8.5	1,495,018	12,665,311	5.052	.596	5.052	.596	2.618	.309	100.0
1932	2,554,996	2,554,996	1,322,650	51.77	4,697	139	8.5	651,822	5,559,864	3.920	.460	3.920	.460	2.029	.238	100.0
1933	2,433,949	2,433,949	1,254,603	51.55	4,822	121	8.3	583,896	4,832,064	4.168	.504	4.168	.504	2.149	.260	99.9
1934	5,039,144	5,039,144	2,612,255	51.84	4,885	192	8.0	938,068	7,505,151	5.372	.671	5.372	.671	2.785	.348	99.7
1935	5,205,531	5,205,531	2,696,867	51.81	4,391	212	8.0	930,773	7,442,746	5.593	.699	5.593	.699	2.897	.362	100.0
1936	9,177,629	9,177,629	4,756,497	51.83	5,397	250	8.0	1,350,833	10,808,204	6.794	.849	6.794	.849	3.521	.440	100.0
1937	12,085,048	12,085,048	6,224,379	51.50	6,839	252	8.0	1,725,079	13,804,353	7.006	.875	7.006	.875	3.608	.451	100.0

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained[m]			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Wisconsin																
1880	37,000	37,000	19,450[i]	52.57	60	203	n.a.	12,201[e]	n.a.	3.033	n.a.	3.033	n.a.	1.594	n.a.	100.0
1889	837,399	837,399	n.a.	n.a.	1,737	265	n.a.	460,904[g]	n.a.	1.817	n.a.	1.817	n.a.	n.a.	n.a.	100.0
1902	783,996	783,996	422,000	53.83	n.a.	n.a.	n.a.	408,300[i]	n.a.	1.920	n.a.	1.920	n.a.	1.034	n.a.	100.0
1915	1,095,388	1,095,388	582,000	53.1[m]	995	298	8.0	296,510	2,372,085	3.694	0.462	3.694	0.462	1.963	0.245	95.3
1916	1,304,518	1,304,518	689,000	52.8[m]	1,232	298	8.0	367,294	2,938,345	3.552	.444	3.552	.444	1.876	.234	92.3
1917	1,202,235	1,202,235	631,000	52.5[m]	1,289	294	8.0	378,731	3,029,848	3.174	.397	3.174	.397	1.666	.208	100.0
1918	1,089,351	1,089,351	569,000	52.2[m]	1,214	308	8.0	373,880	2,991,051	2.914	.364	2.914	.364	1.522	.190	99.9
1919	1,087,247	1,087,247	575,000	52.7[m]	1,171	310	8.4	363,012	3,047,908	2.995	.357	2.995	.357	1.578	.188	96.3
1920	981,134	981,134	513,000	52.3[m]	1,026	306	8.0	313,982	2,511,850	3.125	.391	3.125	.391	1.634	.204	99.2
1921	257,014	257,014	134,000	52.2[m]	510	336	8.5	171,371	1,453,123	1.500	.177	1.500	.177	.782	.092	99.8
1922	579,416	577,024	305,000	52.9[m]	936	234	8.5	219,157	1,861,244	2.644	.311	2.633	.310	1.392	.164	95.5
1923	879,494	871,416	440,402	50.54	696	287	8.5	200,025	1,693,390	4.397	.519	4.357	.515	2.202	.260	96.7
1924	690,058	690,058	359,154	52.06	573	277	8.5	159,003	1,357,559	4.340	.508	4.340	.508	2.259	.265	98.6
1925	817,149	817,149	426,080	52.14	703	251	8.5	176,161	1,504,910	4.639	.543	4.639	.543	2.419	.283	99.9
1926	1,322,776	1,322,776	673,980	51.33	1,101	298	8.4	327,656	2,748,452	4.037	.481	4.037	.481	2.072	.247	100.0
1927	1,091,118	1,091,118	559,886	51.31	995	302	8.4	300,045	2,529,776	3.637	.431	3.637	.431	1.866	.221	99.9
1928	1,284,592	1,284,592	671,226	52.25	1,024	257	8.6	263,226	2,272,370	4.880	.566	4.880	.565	2.550	.295	99.9
1929	1,608,571	1,608,571	842,904	52.40	989	300	8.7	296,869	2,569,321	5.418	.626	5.418	.626	2.839	.328	99.9
1930	1,321,360	1,321,360	698,394	52.85	828	297	8.5	246,151	2,094,179	5.369	.631	5.368	.631	2.837	.333	99.9
1931	879,832	879,832	467,061	53.09	542	276	8.4	149,814	1,255,668	5.873	.701	5.873	.701	3.118	.372	100.0
1932	430,140	430,140	230,436	53.57	388	188	8.5	72,800	616,639	5.909	.698	5.909	.698	3.165	.374	100.0
1933	228,487	228,487	122,063	53.42	227	247	8.4	56,088	471,945	4.074	.484	4.074	.484	2.176	.259	100.0
1934	602,005	602,005	322,510	53.57	404	261	7.9	105,525	835,384	5.705	.721	5.705	.721	3.056	.386	100.0
1935	788,483	788,483	422,190	53.54	535	249	8.0	132,974	1,063,798	5.930	.741	5.930	.741	3.175	.397	100.0
1936	969,522	969,522	518,267	53.46	532	264	8.0	140,624	1,124,995	6.894	.862	6.894	.862	3.685	.461	100.0
1937	1,158,602	1,155,602	617,846	53.47	626	262	8.0	164,203	1,313,634	7.038	.880	7.038	.880	3.763	.470	99.9

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						Percent of industry on which based[d]
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				
		Gross tons	Iron (natural) contained			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Alabama																
1880	n.a.	171,139	86,731[l]	50.68	750	173	n.a.	130,045[e]	n.a.	n.a.	n.a.	1.316	n.a.	0.667	n.a.	96.1
1889	n.a.	1,570,319	n.a.	n.a.	3,019	238	n.a.	718,059[f]	n.a.	n.a.	n.a.	2.187	n.a.	n.a.	n.a.	100.0
1902	n.a.	3,574,474	n.a.	n.a.	n.a.	n.a.	n.a.	1,459,200[i]	n.a.	n.a.	n.a.	2.450	n.a.	n.a.	n.a.	100.0
1915	8,111,000	5,309,354	n.a.	n.a.	5,074	269	10.0	1,365,101	13,651,011	5.942	0.594	3.889	0.389	n.a.	n.a.	96.8
1916	9,929,000	6,747,901	n.a.	n.a.	7,253	297	10.0	2,152,469	21,524,718	4.613	.461	3.135	.313	n.a.	n.a.	98.9
1917	11,118,000	7,037,707	n.a.	n.a.	8,887	282	10.0	2,507,600	25,076,020	4.434	.443	2.807	.281	n.a.	n.a.	98.8
1918	9,334,000	5,754,624	n.a.	n.a.	7,999	320	10.0	2,560,602	25,605,998	3.645	.365	2.247	.225	n.a.	n.a.	97.0
1919	7,742,000	5,053,035	n.a.	n.a.	8,348	301	10.0	2,509,774	25,097,753	3.085	.308	2.013	.201	n.a.	n.a.	96.3
1920	9,650,000	5,894,011	n.a.	n.a.	7,257	301	10.0	2,186,093	21,860,954	4.414	.441	2.696	.270	n.a.	n.a.	97.1
1921	4,692,000	2,876,141	n.a.	n.a.	4,864	174	10.0	847,113	8,471,135	5.539	.554	3.395	.340	n.a.	n.a.	99.9
1922	8,487,000	5,234,568	n.a.	n.a.	6,390	263	9.8	1,677,976	16,511,214	5.040	.512	3.120	.317	n.a.	n.a.	98.3
1923	11,781,000	6,783,146	2,525,067	37.23	7,710	294	10.3	2,263,760	23,303,607	5.204	.506	2.996	.291	1.115	0.108	97.6
1924	10,715,000	6,993,613	2,584,058	36.95	7,534	268	10.0	2,021,170	20,186,952	5.301	.531	3.460	.346	1.278	.128	98.8
1925	11,089,000	7,093,250	2,631,540	37.10	7,155	295	10.0	2,111,537	21,115,364	5.252	.525	3.359	.336	1.246	.125	99.3
1926	10,862,000	6,847,789	2,552,216	37.27	6,460	288	10.4	1,857,783	19,340,090	5.847	.562	3.686	.354	1.374	.132	99.5
1927	10,109,000	6,445,464	2,384,539	37.00	6,172	273	10.4	1,687,510	17,547,854	5.990	.576	3.820	.367	1.413	.136	99.6
1928	10,304,000	6,307,844	2,357,532	37.37	5,979	259	10.2	1,550,459	15,822,034	6.646	.651	4.068	.399	1.521	.149	99.4
1929	10,367,000	6,453,075	2,417,333	37.47	5,498	265	10.0	1,458,896	14,598,242	7.106	.710	4.423	.442	1.657	.166	99.8
1930	9,410,000	5,738,478	2,150,895	37.48	5,137	257	9.7	1,320,789	12,876,652	7.125	.731	4.345	.446	1.628	.167	99.6
1931	5,151,000	3,615,144	1,345,867	37.23	3,672	197	9.6	722,793	6,926,226	7.127	.744	5.002	.522	1.862	.194	99.0
1932	1,634,000	1,374,534	513,722	37.37	2,882	106	9.7	305,039	2,960,020	5.357	.552	4.506	.464	1.684	.174	99.2
1933	3,749,000	2,153,457	799,099	37.46	2,940	171	8.9	504,146	4,485,588	7.436	.836	4.232	.476	1.585	.178	99.4
1934	3,860,000	2,343,819	881,583	37.61	2,927	198	8.0	579,796	4,638,936	6.657	.832	4.042	.506	1.521	.190	97.6
1935	4,122,000	3,277,535	1,200,808	36.63	3,264	212	8.0	691,090	5,538,167	5.964	.744	4.743	.592	1.737	.217	99.5
1936	5,060,000	4,179,967	1,558,912	37.29	4,063	213	8.1	864,664	7,028,402	5.840	.719	4.834	.595	1.803	.222	97.6
1937	7,601,000	6,307,581	2,317,993	36.75	4,906	253	8.1	1,242,651	10,024,673	6.117	.758	5.076	.629	1.865	.231	98.0

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						Percent of industry on which based[d]
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				
		Gross tons	Iron (natural) contained			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
Northeastern District (New York, New Jersey, and Pennsylvania)																
1880	n.a.	3,754,620	1,855,619[1]	49.42	19,290	234	n.a.	4,511,928[e]	n.a.	n.a.	n.a.	0.832	n.a.	0.411	n.a.	90.7
1889	n.a.	3,223,281	n.a.	n.a.	9,010	248	n.a.	2,230,204[f]	n.a.	n.a.	n.a.	1.445	n.a.	n.a.	n.a.	100.0
1902	n.a.	1,820,132	n.a.	n.a.	n.a.	n.a.	n.a.	1,129,500[1]	n.a.	n.a.	n.a.	1.611	n.a.	n.a.	n.a.	100.0
1915	2,270,000	1,777,388	n.a.	n.a.	3,550	293	8.9	1,039,569	9,243,364	2.184	0.246	1.710	0.192	n.a.	n.a.	96.6
1916	3,199,000	2,394,942	n.a.	n.a.	4,360	279	8.6	1,217,759	10,525,575	2.627	.304	1.967	.228	n.a.	n.a.	97.9
1917	3,275,000	2,340,960	n.a.	n.a.	4,430	282	8.7	1,249,527	10,924,098	2.621	.300	1.873	.214	n.a.	n.a.	96.8
1918	2,647,000	1,852,304	n.a.	n.a.	3,938	288	8.8	1,136,070	9,993,478	2.330	.265	1.630	.185	n.a.	n.a.	97.6
1919	2,679,000	1,903,090	n.a.	n.a.	4,163	265	8.6	1,104,498	9,547,442	2.426	.281	1.723	.199	n.a.	n.a.	91.8
1920	2,853,000	2,085,959	n.a.	n.a.	3,407	288	8.9	980,996	8,778,907	2.908	.325	2.126	.238	n.a.	n.a.	94.6
1921	916,000	675,226	n.a.	n.a.	2,333	125	8.5	292,459	2,479,884	3.132	.369	2.309	.272	n.a.	n.a.	93.1
1922	1,628,000	1,315,576	n.a.	n.a.	2,975	194	8.6	577,247	4,976,383	2.820	.327	2.279	.264	n.a.	n.a.	84.7
1923	2,277,701	1,843,096	946,525	51.36	2,418	220	8.7	531,780	4,634,464	4.283	.491	3.466	.398	1.780	0.204	89.1
1924	1,253,061	1,128,237	549,078	48.67	1,785	152	8.9	270,648	2,413,316	4.630	.519	4.169	.468	2.029	.228	77.3
1925	1,518,604	1,300,431	611,833	47.05	1,509	223	8.7	336,770	2,939,278	4.509	.517	3.861	.442	1.817	.208	91.9
1926	2,395,864	1,943,471	997,575	51.33	2,077	250	8.8	519,808	4,594,321	4.609	.521	3.739	.423	1.919	.217	94.7
1927	2,984,673	2,244,254	1,124,976	50.13	2,213	293	8.7	649,069	5,633,706	4.598	.530	3.458	.398	1.733	.200	99.0
1928	2,381,804	1,986,959	1,034,908	52.09	1,977	244	8.5	482,305	4,093,401	4.938	.582	4.120	.485	2.146	.253	99.1
1929	2,843,595	2,195,601	1,140,708	51.95	2,097	269	8.5	563,692	4,787,157	5.045	.594	3.895	.459	2.024	.238	98.6
1930	3,107,186	2,248,682	1,238,005	55.05	2,731	262	8.5	714,189	6,058,999	4.351	.513	3.149	.371	1.733	.204	99.8
1931	1,224,797	936,960	509,590	54.39	1,688	175	8.7	295,217	2,570,050	4.149	.477	3.174	.365	1.726	.198	99.9
1932	218,990	165,009	78,960	47.85	595	101	9.0	58,906	530,602	3.718	.413	2.801	.311	1.340	.149	98.7
1933	445,826	396,228	190,213	48.01	310	186	8.2	57,625	474,644	7.737	.939	6.876	.835	3.301	.401	99.7
1934	1,222,710	908,944	459,258	50.53	1,263	142	8.0	178,930	1,422,916	6.833	.859	5.080	.639	2.567	.323	99.9
1935	1,634,878	1,349,247	662,856	49.11	1,029	179	8.0	183,856	1,471,869	8.892	1.111	7.339	.917	3.604	.450	100.0
1936	2,931,949	2,069,764	1,110,439	53.65	1,599	257	8.4	410,521	3,430,512	7.142	.855	5.042	.603	2.705	.324	100.0
1937	4,400,681	3,145,177	1,637,436	52.06	2,615	284	8.1	743,698	6,015,342	5.917	.732	4.229	.523	2.202	.272	100.0

(Footnotes at end of table.)

Table A-4.- QUANTITY AND TENOR OF ORE PRODUCED, EMPLOYMENT, AND OUTPUT PER MAN AT IRON MINES AND BENEFICIATING PLANTS, 1880-1937, BY STATE[a] - Continued

(Exclusive after 1889 of ore containing 5 percent or more manganese)

State and Year	Production				Employment[b]					Average output per man (gross tons)						
	Crude ore[c] (partly estimated) gross tons	Merchantable ore			Average number of men employed	Average time employed		Units of labor		Crude ore (partly estimated)		Merchantable ore				Percent of industry on which based[d]
		Gross tons	Iron (natural) contained			Shifts per man	Hours per shift	Total man-shifts	Total man-hours	Per shift	Per hour	Per shift	Per hour	Iron (natural) contained		
			Gross tons	Percent										Per shift	Per hour	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				(3)÷(2)		(8)÷(5)	(9)÷(8)			(1)÷(8)	(1)÷(9)	(2)÷(8)	(2)÷(9)	(3)÷(8)	(3)÷(9)	
All other States[n]																
1880	n.a.	1,516,789	708,379[l]	46.70	9,690	202	n.a.	1,958,228[e]	n.a.	n.a.	n.a.	0.775	n.a.	0.362	n.a.	69.8
1889	n.a.	2,166,365	n.a.	n.a.	8,382	214	n.a.	1,792,709[f]	n.a.	n.a.	n.a.	1.208	n.a.	n.a.	n.a.	100.0
1902	n.a.	3,102,668	n.a.	n.a.	n.a.	n.a.	n.a.	1,840,346[i]	n.a.	n.a.	n.a.	1.686	n.a.	n.a.	n.a.	100.0
1915	1,921,000	1,365,184	n.a.	n.a.	3,919	238	9.3	932,597	8,637,845	2.06	0.222	1.464	0.158	n.a.	n.a.	73.3
1916	3,033,000	2,063,873	n.a.	n.a.	5,157	243	9.6	1,250,761	11,969,226	2.42	.253	1.650	.172	n.a.	n.a.	81.6
1917	3,145,000	2,244,116	n.a.	n.a.	5,210	245	9.4	1,278,991	11,985,449	2.46	.262	1.755	.187	n.a.	n.a.	85.5
1918	3,124,000	2,108,689	n.a.	n.a.	4,402	260	9.4	1,146,595	10,798,397	2.72	.289	1.839	.195	n.a.	n.a.	79.7
1919	2,157,000	1,482,490	n.a.	n.a.	3,574	218	9.7	780,486	7,552,316	2.76	.286	1.899	.196	n.a.	n.a.	82.3
1920	2,490,000	1,679,446	n.a.	n.a.	4,304	221	9.5	950,632	9,059,703	2.62	.275	1.767	.185	n.a.	n.a.	55.1
1921	898,000	587,780	n.a.	n.a.	2,223	147	8.7	326,166	2,851,976	2.14	.245	1.802	.206	n.a.	n.a.	78.1
1922	1,241,000	778,821	n.a.	n.a.	1,907	176	8.7	336,249	2,909,424	3.69	.427	2.316	.268	n.a.	n.a.	77.6
1923	2,873,000	1,331,020	638,809	47.99	2,410	251	9.0	604,360	5,415,303	4.75	.531	2.202	.246	1.057	0.118	76.5
1924	1,930,000	1,202,671	597,559	49.69	1,795	256	8.8	460,140	4,045,430	4.19	.477	2.614	.297	1.299	.148	76.0
1925	2,298,000	1,350,394	687,263	50.89	1,621	235	8.7	380,325	3,315,597	6.04	.693	3.551	.407	1.807	.207	86.0
1926	2,276,000	1,559,097	811,753	52.07	1,379	270	8.6	371,974	3,196,701	6.12	.712	4.191	.488	2.182	.254	96.9
1927	2,085,000	1,424,047	723,473	50.80	1,466	284	8.6	416,453	3,554,560	5.01	.587	3.419	.401	1.737	.204	95.3
1928	2,196,000	1,376,704	695,774	50.54	1,401	295	8.4	413,284	3,492,109	5.31	.629	3.331	.394	1.684	.199	97.4
1929	2,345,000	1,553,218	784,592	50.51	1,357	274	8.4	372,037	3,113,660	6.30	.753	4.175	.499	2.109	.252	93.9
1930	1,711,000	1,038,119	528,393	50.90	806	221	8.3	178,382	1,486,848	9.59	1.151	5.820	.698	2.962	.355	96.6
1931	1,000,000	701,982	361,470	51.49	1,020	170	8.2	173,510	1,414,610	5.76	.707	4.046	.496	2.083	.256	87.3
1932	168,000	167,946	88,487	52.69	414	87	8.2	36,131	297,600	4.65	.565	4.648	.564	2.449	.297	86.3
1933	423,000	412,471	217,183	52.65	277	172	8.1	47,551	384,288	8.90	1.101	8.674	1.073	4.567	.565	98.6
1934	308,000	303,834	163,096	53.68	317	115	8.1	36,415	296,108	8.46	1.040	8.344	1.026	4.479	.551	93.1
1935	577,000	544,833	284,014	52.13	334	166	8.0	55,558	445,537	10.39	1.295	9.807	1.223	5.112	.637	99.4
1936	814,000	757,799	404,407	53.37	518	167	8.5	86,291	729,675	9.43	1.116	8.782	1.039	4.687	.554	98.5
1937	1,013,000	985,155	517,112	52.60	588	148	8.4	87,032	727,138	11.64	1.393	11.296	1.352	5.942	.711	94.4

[a]Data for 1880 from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), pp. 64-7; for 1889 from Eleventh Census of

shown. The estimated number comparable to other years (44,800) was derived by dividing the total number of man-shifts worked (11,650,946) by an assumed average of 260 shifts per man. Two hundred eighty shifts per man, derived by straight-line interpolation between 1889 and 1915, seemed

[a]Data for 1880 from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), pp. 64-7; for 1889 from Eleventh Census of the United States: 1890, "Report on Mineral Industries" (1892), pp. 10, 17-8; for 1902 from Special Reports of the Census Office, "Mines and Quarries: 1902" (U. S. Dept. Com. and Labor, Bur. Census, 1906), pp. 428-9; for 1915-37 from reports of iron-mining companies to the U. S. Bureau of Mines. For some years the sum of the State data does not equal the regional or National total because of rounding of figures.

[b]Exclusive of administrative and clerical employees. Employment data were estimated for a small portion of the total production for which these data were not reported in 1880 and 1915-37. The production with employment data reported represents a large proportion of the total production as is indicated in column 16 and even a large revision of the estimates would not materially affect the totals. The employment estimates for mines for which employment data were lacking assumed a similar rate of output per man as in other mines in the same State using the same general method of mining (e.g., open-pit or underground). In the period 1923-37 it was possible to complete the record of employment for some iron mines from reports of Mine Inspectors in various important iron-ore-producing counties.

[c]Crude ore mined was partly estimated for all years. Data for 1915-22 involved more estimates than for subsequent years. Most of the estimates are of the iron-bearing material produced at most brown-ore mines, as only the cleaned ore is weighed at these mines. The quantity of brown ore mined annually is comparatively small (averaged 1.3 percent annually during 1923-32), so that even a major error in calculations would not seriously impair the value of the principal trends shown.

[d]Calculated for each year by dividing the quantity of merchantable ore covered in the study by the total quantity of merchantable ore produced. Merchantable ore covered in the study is that ore for which employment data were reported and from which the basic tons-per-man ratios were computed.

[e]The number of man-shifts worked in this year was derived from data published in the Tenth Census of number of men employed in "regular" establishments, and percentages of a 300-day year worked by these men. Man-shifts for "irregular" establishments (that produced about 11 percent of the total merchantable ore in the United States) were estimated by multiplying their output by the average man-shifts per ton for the regular establishments.

[f]As estimated in the Eleventh Census: 1890, "Report on Mineral Industries," p. 10, from the yield of pig iron from domestic iron ore consumed in blast furnaces.

[g]The number of man-shifts worked was derived from data published in ibid., pp. 13-8 on the number of men employed (classified by occupations above and below ground) and the average numbers of days worked in the year. Foremen were excluded for comparability with other years.

[h]Estimated. The Census report for 1902 had reduced all employees to a 300-day per year basis, the number of such full-time employees being 38,851. Since the industry does not usually average 300 working days per year, the number of employees in comparison with other years was larger than shown. The estimated number comparable to other years (44,800) was derived by dividing the total number of man-shifts worked (11,650,946) by an assumed average of 260 shifts per man. Two hundred sixty shifts per man, derived by straight-line interpolation between 1889 and 1915, seemed to be reasonable in the light of such clues as were available.

[i]Derived from data published in Special Reports of the Census Office, "Mines and Quarries: 1902," pp. 399-402 on the number of 300-day employees by multiplying the latter by 300. Substantially the same result was derived from data on total wages paid and average daily wage rates. Total wages paid in the United States, divided by the weighted average of daily wage rates gave a total of 11,410, 595 man-days compared with 11,650,946 man-days obtained by multiplying the number of full-time (300-day) employees by 300. An estimated 4,350 man-shifts used to produce 13,275 tons of manganiferous ore are excluded from this table.

[j]Data for percentage of iron contained in ore produced for the period 1902-22 are not strictly comparable with subsequent years. They represent the iron content of ore shipments rather than production, and represent, moreover, both iron ore proper and small quantities of manganiferous ores containing 2 percent or more manganese. The iron content of manganiferous ore is lower than for iron ore proper, ranging from 37 to almost 52 percent. The use of data including manganiferous ore, however, may be taken as representative of iron ore since the quantity of manganiferous ore included is very small, averaging 3.2 percent of the total ore from Minnesota, and 5.9 percent of the total ore from Michigan and Wisconsin. Data for 1902-22 are from Lake Superior Iron Ores: 1938 (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), pp. 190-300.

[k]Represents the average iron content of ore shipped from Marquette, Menominee, and Gogebic ranges. A part of the Gogebic and Menominee ranges are in Wisconsin but their inclusion does not materially alter the results since the production from the Wisconsin portion of these ranges amounts to less than 10 percent of the total output from Michigan and the average iron content is probably similar.

[l]As reported in the Tenth Census: 1880, Vol. XV, p. 19, after converting short tons to gross tons.

[m]Data for percentage of iron contained in the ore produced in Wisconsin for 1915-22 are adapted from the source cited in footnote j. The data are approximate, being derived from the percentage of iron contained in the ores produced in the Menominee and Gogebic ranges, weighted by the production from the Wisconsin portions of each of these ranges.

[n]Includes California, Colorado, Connecticut, Georgia, Idaho, Iowa, Maryland, Massachusetts, Mississippi, Missouri, Montana, Nevada, New Mexico, North Carolina, Ohio, Tennessee, Utah, Virginia, Washington, and Wyoming. Some of these States are regular producers while others produce sporadically.

n.a. Data not available.

Table A-5.- PRODUCTION, EMPLOYMENT, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES IN THE UNITED STATES, 1915-37[a]

(Exclusive of ore containing 5 percent or more manganese)

Year	Open-pit mines[b]							Underground mines[b]						
	Merchantable ore produced (Gross tons)	Average number of men employed[c]	Average time employed[d]		Units of labor		Tons per man-hour[f]	Merchantable ore produced (Gross tons)	Average number of men employed[c]	Average time employed[d]		Units of labor		Tons per man-hour[f]
			Shifts per man	Hours per shift	Total man-shifts	Total man-hours[e]				Shifts per man	Hours per shift	Total man-shifts	Total man-hours[e]	
	(1)	(2) (5)÷(3)	(3)	(4)	(5) (6)÷(4)	(6)	(7) (1)÷(6)	(8)	(9) (12)÷(10)	(10)	(11)	(12)	(13) (13)÷(11)	(14) (8)÷(13)
1915	22,161,324	8,503	239	9.7	2,031,058	19,773,502	1.121	33,365,166	34,882	280	8.8	9,777,418	85,754,875	0.389
1916	34,864,806	13,635	274	8.5	3,737,103	31,592,641	1.104	40,302,866	43,414	274	9.2	11,899,311	109,160,525	.369
1917	35,449,586	15,391	256	9.9	3,936,960	38,885,964	.912	39,839,265	45,203	288	8.8	13,032,661	114,699,207	.347
1918	35,707,746	15,700	277	9.9	4,352,734	42,894,283	.832	33,960,532	39,974	299	8.8	11,949,642	105,711,349	.321
1919	28,214,130	10,563	251	10.0	2,649,445	26,575,958	1.062	32,751,288	41,217	287	8.8	11,828,399	104,491,934	.313
1920	32,664,249	12,142	280	9.9	3,401,923	33,813,947	.966	34,940,216	38,448	290	8.9	11,136,208	99,638,264	.351
1921	13,846,084	7,375	246	10.0	1,815,561	18,169,619	.762	15,644,894	24,973	198	8.7	4,933,736	42,977,227	.364
1922	24,700,930	9,798	249	9.3	2,444,556	22,719,541	1.087	22,427,597	25,960	251	8.7	6,509,862	56,719,020	.395
1923	39,123,078	13,049	262	9.8	3,421,328	33,408,407	1.171	30,228,364	28,245	297	8.9	8,376,354	74,142,837	.408
1924	25,587,190	11,048	246	9.5	2,713,646	25,866,611	.989	28,680,229	27,717	270	8.7	7,488,032	65,457,887	.438
1925	29,971,378	9,762	231	9.6	2,252,149	21,511,194	1.393	31,936,619	25,995	285	8.7	7,413,728	64,829,490	.493
1926	34,551,607	9,150	219	9.7	2,001,211	19,362,915	1.784	33,071,393	25,249	293	8.8	7,394,147	64,862,609	.510
1927	30,850,488	10,253	200	9.5	2,046,689	19,389,449	1.591	30,890,612	24,502	291	8.8	7,131,290	62,615,312	.493
1928	33,018,764	7,832	244	9.5	1,914,067	18,189,939	1.815	29,178,324	22,406	272	8.7	6,094,580	53,213,692	.548
1929	40,653,836	8,521	269	9.7	2,289,132	22,133,582	1.837	32,373,884	22,242	285	8.7	6,349,102	54,977,504	.589
1930	28,992,931	8,518	228	10.0	1,944,977	19,378,353	1.496	29,415,733	22,457	271	8.6	6,092,119	52,241,762	.563
1931	13,999,389	5,991	196	9.8	1,176,705	11,545,803	1.212	17,132,113	16,876	203	8.6	3,419,799	29,382,480	.583
1932	3,434,082	2,340	162	9.7	380,224	3,688,357	.931	6,412,834	10,309	140	8.8	1,447,778	12,738,652	.503
1933	11,335,809	4,795	142	8.4	678,878	5,686,760	1.993	6,217,379	10,330	140	8.5	1,442,616	12,244,729	.508
1934	14,037,201	5,334	184	8.0	981,359	7,839,730	1.791	10,550,415	11,179	197	8.0	2,204,873	17,638,710	.598
1935	17,926,848	4,121	218	8.1	898,171	7,258,465	2.470	12,613,404	10,866	219	8.0	2,379,824	19,023,228	.663
1936	30,806,433	7,249	197	8.1	1,426,775	11,602,787	2.655	17,982,312	13,057	244	8.0	3,190,621	25,643,796	.701
1937	47,461,101	9,185	212	8.1	1,944,637	15,788,218	3.005	24,642,447	16,760	266	8.0	4,452,194	35,627,975	.692

[a]Includes beneficiating plants at the mines. Data from reports of iron-mining

[d]Exclusive of some of the mines with a combination of mining methods which

[a]Includes beneficiating plants at the mines. Data from reports of iron-mining companies to the U. S. Bureau of Mines.

[b]The reports for some of the mines which used a combination of open-pit and underground mining methods did not completely separate production and man-hours for these two branches of mining. Most of the combination mines are in Minnesota and the separation was partly estimated for this State on the basis of data in Annual Reports of Inspectors of Mines for Itasca, St. Louis, and Crow Wing Counties of Minnesota. Other estimates were based on output per man-hour at open-pit and underground mines in the same mines in previous or succeeding years, or in the same year in neighboring mines, and from other clues.

[c]Includes an estimate of men at open-pit or underground operations of mines that used a combination of these methods and did not report employment separately. The estimates assume that men at these mines averaged the same number of shifts per man per year as the average for open-pit or underground mines for which separate employment data were reported.

[d]Exclusive of some of the mines with a combination of mining methods which did not report employment at open-pit and underground mines separately. The production of these mines during the 23-year period 1915-37 amounted to about 12 percent of the United States total; their open-pit production was 15 percent of the United States total from open pits, and their underground production was 8 percent of the United States total from underground.

[e]Man-hours were estimated for some production for which these data were not reported. The man-hour estimates were made by dividing production for which employment data were lacking, by the tons per man-hour for the mines for which employment data were reported and which were located in the same area and used the same mining method. See table A-6 for percentage of industry on which based.

[f]See table A-6 for percentage of industry on which based.

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a]

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore		Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore		Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	Gross tons	Percent of total				Gross tons	Percent of total							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
United States														
1909	24,150,491	46.7	n.a.	n.a.	100.0	27,567,429	53.3	n.a.	n.a.	100.0	51,717,920	n.a.	n.a.	100.0
1915	22,161,324	39.9	19,773,502	1.121	98.8	33,365,166	60.1	85,754,875	0.389	92.3	55,526,490	105,528,377	0.526	94.9
1916	34,864,806	46.4	31,592,641	1.104	98.0	40,302,866	53.6	109,160,525	.369	98.4	75,167,672	140,753,166	.534	98.2
1917	35,449,586	47.1	38,885,964	.912	95.2	39,839,265	52.9	114,699,207	.347	96.9	75,288,851	153,585,171	.490	96.1
1918	35,707,746	51.3	42,894,283	.832	92.5	33,950,532	48.7	105,711,349	.321	96.3	69,658,278	148,605,632	.469	94.4
1919	28,214,130	46.3	26,575,958	1.062	98.2	32,751,288	53.7	104,491,934	.313	95.7	60,965,418	131,067,892	.465	96.9
1920	32,664,249	48.3	33,813,947	.966	83.5	34,940,216	51.7	99,638,264	.351	92.7	67,604,465	133,452,211	.507	88.4
1921	13,846,084	47.0	18,169,619	.762	96.8	15,644,894	53.0	42,977,227	.364	98.6	29,490,978	61,146,846	.482	97.8
1922	24,700,930	52.4	22,719,541	1.087	97.4	22,427,597	47.6	56,719,020	.395	96.3	47,128,527	79,438,561	.593	96.9
1923	39,123,078	56.4	33,408,407	1.171	97.0	30,228,364	43.6	74,142,837	.408	95.9	69,351,442	107,551,244	.645	96.5
1924	25,587,190	47.2	25,866,611	.989	97.5	28,680,229	52.8	65,457,887	.438	97.7	54,267,419	91,324,498	.594	97.7
1925	29,971,378	48.4	21,511,194	1.393	97.6	31,936,619	51.6	64,829,490	.493	98.9	61,907,997	86,340,684	.717	98.3
1926	34,551,607	51.1	19,362,915	1.784	97.3	33,071,393	48.9	64,862,609	.510	98.8	67,623,000	84,225,524	.803	98.0
1927	30,850,488	50.0	19,389,449	1.591	96.6	30,890,612	50.0	62,615,312	.493	98.4	61,741,100	82,004,761	.753	97.5
1928	33,018,764	53.1	18,189,939	1.815	95.1	29,178,324	46.9	53,213,692	.548	99.0	62,197,088	71,403,631	.871	96.9
1929	40,653,836	55.7	22,133,582	1.837	97.9	32,373,884	44.3	54,977,504	.589	97.2	73,027,720	77,111,086	.947	97.5
1930	28,992,931	49.6	19,378,353	1.496	98.8	29,415,733	50.4	52,241,762	.563	99.8	58,408,664	71,620,115	.816	99.3
1931	13,999,389	45.0	11,545,803	1.212	98.7	17,132,113	55.0	29,382,480	.583	99.9	31,131,502	40,928,283	.761	99.3
1932	3,434,082	34.9	3,688,357	.931	91.5	6,412,834	65.1	12,738,652	.503	100.0	9,846,916	16,427,009	.599	97.0
1933	11,335,809	64.6	5,686,760	1.993	99.2	6,217,379	35.4	12,244,729	.508	100.0	17,553,188	17,931,489	.979	99.5
1934	14,037,201	57.1	7,839,730	1.791	98.9	10,550,415	42.9	17,638,710	.598	97.7	24,587,616	25,478,440	.965	98.4
1935	17,926,848	58.7	7,258,465	2.470	100.0	12,613,404	41.3	19,023,228	.663	100.0	30,540,252	26,281,693	1.162	99.9
1936	30,806,433	63.1	11,602,787	2.655	99.6	17,982,312	36.9	25,643,796	.701	100.0	48,788,745	37,246,583	1.310	99.8
1937	47,451,101	65.8	15,788,218	3.005	99.3	24,642,447	34.2	35,627,975	.692	99.9	72,093,548	51,416,193	1.402	99.5
1938[e]	13,901,590	48.9	7,743,000	1.795	99.1	14,545,692	51.1	22,645,000	.642	100.0	28,447,282	30,388,000	.936	99.5

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Minnesota														
1909	19,869,105	82.3	n.a.	n.a.	100.0	9,258,813	33.6	n.a.	n.a.	100.0	29,127,918	n.a.	n.a.	100.0
1915	19,278,946	87.0	11,576,946	1.665	99.2	14,185,714	42.5	25,410,103	0.558	96.4	33,464,660	36,987,049	0.905	98.0
1916	31,087,331	89.2	18,425,272	1.687	99.4	13,498,091	33.5	26,514,416	.509	99.2	44,585,422	44,939,688	.992	99.4
1917	30,154,382	85.1	24,501,101	1.231	95.4	14,440,850	36.2	30,311,205	.476	97.0	44,595,232	54,812,306	.814	95.9
1918	30,743,370	86.1	28,670,427	1.072	92.6	11,210,599	33.0	24,919,156	.500	94.2	41,953,969	53,589,583	.783	93.0
1919	24,626,218	87.3	16,533,431	1.489	99.2	11,374,408	34.7	25,536,367	.445	94.1	36,000,626	42,069,798	.856	97.6
1920	28,271,096	86.6	22,909,755	1.234	83.5	11,182,077	32.0	23,844,848	.469	86.1	39,453,173	46,754,603	.844	84.2
1921	12,748,236	92.1	16,255,695	.784	97.1	5,063,089	32.4	10,262,568	.493	99.6	17,811,325	26,518,263	.672	97.8
1922	21,835,654	88.4	17,149,001	1.273	97.8	6,933,306	30.9	11,917,102	.582	97.3	28,768,960	29,066,103	.990	97.7
1923	35,299,051	90.2	25,351,971	1.392	97.7	9,049,245	29.9	16,127,677	.561	96.9	44,348,296	41,479,648	1.069	97.5
1924	22,612,357	88.4	19,919,562	1.135	98.9	9,289,728	32.4	15,318,487	.606	98.8	31,902,085	35,238,049	.905	98.9
1925	26,511,716	88.5	15,686,480	1.690	98.3	10,344,528	32.4	14,601,507	.708	99.8	36,856,244	30,287,987	1.217	98.7
1926	30,491,844	88.2	13,141,691	2.320	97.4	10,209,769	30.9	15,004,414	.680	99.7	40,701,613	28,146,105	1.446	98.0
1927	26,760,898	86.7	14,390,310	1.860	96.4	8,700,240	28.2	13,549,757	.642	98.2	35,461,138	27,940,067	1.269	96.8
1928	29,145,935	88.3	13,417,295	2.172	94.7	8,418,070	28.9	11,912,007	.707	99.0	37,564,005	25,329,302	1.483	95.7
1929	36,148,858	89.0	17,034,444	2.122	97.7	9,612,000	29.7	12,293,883	.782	96.1	45,760,858	29,328,327	1.560	97.4
1930	25,522,212	88.0	15,401,770	1.657	98.8	8,995,536	30.6	12,142,843	.741	99.6	34,517,748	27,544,613	1.253	99.0
1931	12,055,312	86.1	8,529,431	1.413	99.5	5,389,691	31.5	7,566,987	.712	99.7	17,445,003	16,096,418	1.084	99.6
1932	2,921,484	85.1	2,961,667	.986	91.1	2,232,807	34.8	3,500,537	.638	100.0	5,154,291	6,462,204	.798	94.9
1933	10,405,709	91.8	4,583,625	2.270	99.3	1,542,887	24.8	2,699,435	.572	100.0	11,948,596	7,283,060	1.641	99.4
1934	12,308,109	87.7	6,193,801	1.987	95.5	3,081,761	29.2	4,586,144	.672	92.1	15,389,870	10,779,945	1.428	98.0
1935	16,739,954	87.8	5,550,675	2.836	100.0	3,634,669	28.8	4,768,901	.762	100.0	19,374,623	10,319,576	1.877	100.0
1936	27,348,475	88.8	8,926,364	3.064	100.0	4,285,589	23.8	5,198,431	.824	100.0	31,634,064	14,124,795	2.240	100.0
1937	42,734,562	90.1	12,650,727	3.378	99.6	5,682,433	23.1	6,880,326	.826	99.8	48,416,985	19,531,053	2.479	99.6

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Mesabi Range														
1915	18,697,594	84.4	10,655,203	1.755	99.4	12,104,815	36.3	20,456,117	0.592	95.8	30,802,409	31,111,320	0.990	98.0
1916	30,385,656	87.2	17,424,672	1.744	99.8	10,939,685	27.1	19,390,913	.564	99.1	41,325,341	36,815,585	1.122	99.6
1917	29,342,934	82.8	23,433,232	1.252	95.2	11,784,389	29.6	23,145,324	.509	96.4	41,127,323	46,578,556	.883	95.6
1918	29,948,883	83.9	27,430,595	1.092	93.2	9,107,094	26.8	19,170,144	.475	93.5	39,055,977	46,600,739	.838	93.3
1919	24,045,637	85.2	15,516,473	1.550	99.2	9,217,317	28.1	19,575,290	.471	93.5	33,262,954	35,091,763	.948	97.6
1920	27,781,882	85.1	22,271,908	1.247	83.3	8,859,998	25.4	17,098,083	.518	82.5	36,641,880	39,369,991	.931	83.2
1921	12,640,872	91.3	16,043,345	.788	97.1	3,739,318	23.9	7,113,669	.526	99.4	16,380,190	23,157,014	.707	97.7
1922	21,412,559	86.7	16,444,723	1.302	97.8	5,292,042	23.6	6,853,968	.772	99.2	26,704,601	23,298,691	1.146	98.0
1923	34,681,107	88.6	24,721,813	1.403	97.6	7,127,911	23.6	12,175,952	.585	96.7	41,809,018	36,897,765	1.133	97.5
1924	22,256,613	87.0	19,479,442	1.143	98.9	7,562,352	26.4	11,603,041	.652	99.1	29,818,965	31,082,483	.959	99.0
1925	26,292,704	87.7	15,025,876	1.750	98.6	8,558,405	26.8	10,943,097	.782	99.9	34,851,109	25,968,973	1.342	99.0
1926	30,126,773	87.2	12,767,529	2.360	97.7	7,871,024	23.8	10,538,732	.747	100.0	37,997,797	23,306,261	1.630	98.2
1927	26,463,092	85.8	14,024,832	1.887	96.3	6,402,942	20.7	9,341,742	.685	99.0	32,866,034	23,366,574	1.407	96.8
1928	28,760,251	87.1	13,052,675	2.203	95.4	6,096,082	20.9	7,878,287	.774	99.2	34,856,333	20,930,962	1.665	96.1
1929	35,500,562	87.3	15,912,737	2.231	98.0	6,870,630	21.2	8,040,272	.855	94.5	42,371,192	23,953,009	1.769	97.5
1930	25,093,937	86.6	14,915,362	1.682	99.2	6,205,963	21.1	7,753,138	.800	99.9	31,299,900	22,668,500	1.381	99.4
1931	11,929,097	85.2	8,277,483	1.441	99.9	3,669,670	21.4	4,876,366	.753	100.0	15,598,767	13,153,849	1.186	99.9
1932	2,651,466	77.2	2,884,747	.919	100.0	1,604,029	25.0	2,347,486	.683	100.0	4,255,495	5,232,233	.813	100.0
1933	10,263,220	90.5	4,450,991	2.306	99.3	1,103,593	17.8	1,723,154	.640	100.0	11,366,813	6,174,145	1.841	99.4
1934	12,116,078	86.3	5,931,201	2.043	99.5	2,299,169	21.8	2,907,625	.791	89.4	14,415,247	8,838,826	1.631	97.9
1935	15,535,643	86.7	5,337,914	2.910	100.0	2,788,052	22.1	4,043,779	.916	100.0	18,323,695	8,381,693	2.186	100.0
1936	26,995,725	87.6	8,726,588	3.094	100.0	3,209,653	17.8	3,361,885	.955	100.0	30,205,378	12,088,473	2.499	100.0
1937	42,277,343	89.1	12,370,548	3.418	99.6	3,993,523	16.2	4,328,163	.923	99.7	46,270,866	16,698,711	2.771	99.6

(Footnotes at end of table.)

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Michigan and Wisconsin														
1909	319,681	1.3	n.a.	n.a.	100.0	12,648,028	45.9	n.a.	n.a.	100.0	12,967,709	n.a.	n.a.	100.0
1915	1,029,317	4.6	935,200	1.101	99.3	12,580,587	37.7	36,073,908	0.349	87.5	13,609,904	37,009,108	0.368	88.4
1916	1,266,237	3.6	2,540,492	.498	73.7	18,109,297	44.9	49,253,467	.368	98.7	19,375,534	51,793,959	.374	97.1
1917	2,356,808	6.6	2,817,690	.836	98.6	16,714,028	42.0	47,969,608	.348	96.4	19,070,836	50,787,298	.376	96.7
1918	2,461,620	6.9	3,063,035	.804	100.0	15,527,072	45.7	45,555,141	.341	97.6	17,988,692	48,618,176	.370	98.0
1919	1,582,220	5.6	2,648,200	.597	99.9	14,943,957	45.6	44,152,383	.338	97.3	16,526,177	46,800,583	.353	97.6
1920	2,084,146	6.4	2,313,282	.901	99.5	16,407,730	47.0	44,684,762	.367	96.6	18,491,876	46,998,044	.393	97.0
1921	522,130	3.8	329,334	1.585	98.9	7,018,376	44.8	20,496,354	.342	98.7	7,540,506	20,825,688	.362	98.7
1922	1,256,680	5.1	705,142	1.782	100.0	9,774,022	43.6	25,270,295	.387	96.5	11,030,602	25,975,437	.425	96.9
1923	1,643,269	4.2	1,696,700	.969	97.5	13,402,615	44.3	31,021,522	.432	95.5	15,045,884	32,718,222	.460	95.7
1924	1,227,408	4.8	1,090,019	1.126	100.0	11,813,405	41.2	28,351,732	.417	97.5	13,040,813	29,441,751	.443	97.7
1925	1,802,255	6.0	976,348	1.846	100.0	13,505,423	42.3	27,706,110	.487	98.0	15,307,678	28,682,458	.534	98.3
1926	2,047,592	5.9	1,164,862	1.758	100.0	14,523,438	43.9	27,783,445	.523	97.7	16,571,030	28,948,307	.572	98.0
1927	2,001,597	6.5	708,666	2.824	99.7	14,164,600	45.8	26,619,908	.532	98.0	16,166,197	27,328,574	.592	98.2
1928	2,009,102	6.1	716,244	2.805	99.4	12,952,474	44.4	21,950,541	.590	98.6	14,961,576	22,666,785	.660	98.7
1929	2,089,410	5.1	1,032,805	2.023	99.0	14,975,558	46.3	24,253,895	.617	97.1	17,064,968	25,286,700	.675	97.3
1930	1,516,097	5.2	1,021,015	1.485	100.0	13,349,540	45.4	22,631,988	.590	99.9	14,865,637	23,653,003	.628	99.9
1931	863,840	6.2	566,365	1.525	100.0	7,568,573	44.1	13,364,614	.567	100.0	8,432,413	13,920,979	.606	100.0
1932	235,248	6.8	183,963	1.279	100.0	2,749,888	42.9	5,992,540	.459	100.0	2,985,136	6,176,503	.483	100.0
1933	304,453	2.7	207,683	1.466	100.0	2,357,983	37.9	5,096,226	.463	99.9	2,662,436	5,303,909	.502	99.9
1934	647,959	4.6	228,578	2.835	97.3	4,993,190	47.3	8,111,957	.616	100.0	5,641,149	8,340,535	.676	99.7
1935	706,694	3.9	243,458	2.903	100.0	5,287,320	41.9	8,263,086	.640	100.0	5,994,014	8,506,544	.705	100.0
1936	1,638,737	5.3	447,816	3.660	100.0	8,508,364	47.3	11,485,383	.741	100.0	10,147,151	11,933,199	.850	100.0
1937	2,046,981	4.3	656,601	3.118	100.0	11,193,669	45.4	14,461,386	.774	100.0	13,240,650	15,117,987	.876	100.0

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Alabama														
1909	1,128,984	4.7	n.a.	n.a.	100.0	3,558,484	12.9	n.a.	n.a.	100.0	4,687,468	n.a.	n.a.	100.0
1915	923,650	4.2	3,740,377	0.247	99.4	4,385,704	13.2	9,910,634	0.442	96.2	5,309,354	13,651,011	0.389	96.8
1916	1,115,039	3.2	4,886,111	.228	96.6	5,632,862	14.0	16,638,607	.339	99.4	6,747,901	21,524,718	.313	98.9
1917	1,086,578	3.1	5,341,192	.203	94.5	5,951,129	14.9	19,734,828	.302	99.5	7,037,707	25,076,020	.281	98.8
1918	769,067	2.2	4,993,170	.154	90.0	4,985,557	14.7	20,612,828	.242	98.0	5,754,624	25,605,998	.225	97.0
1919	608,822	2.2	3,768,175	.162	86.4	4,444,213	13.6	21,329,578	.208	96.6	5,053,035	25,097,753	.201	95.3
1920	724,229	2.2	4,087,998	.177	98.1	5,169,782	14.8	17,772,956	.291	96.9	5,894,011	21,860,954	.270	97.1
1921	228,465	1.6	880,998	.259	99.9	2,647,676	16.9	7,590,137	.349	99.9	2,876,141	8,471,135	.340	99.9
1922	614,074	2.5	3,401,310	.181	91.4	4,620,494	20.6	13,109,904	.352	99.2	5,234,568	16,511,214	.317	98.3
1923	799,266	2.0	3,846,118	.208	86.1	5,983,880	19.8	19,467,489	.308	99.2	6,783,146	23,303,607	.291	97.6
1924	595,494	2.3	2,947,422	.202	91.1	6,398,119	22.3	17,238,550	.371	99.5	6,993,613	20,185,952	.346	98.8
1925	639,376	2.1	2,984,144	.214	92.2	6,453,875	20.2	18,131,220	.356	100.0	7,093,250	21,115,364	.336	99.3
1926	642,338	1.9	3,143,858	.204	98.1	6,205,451	18.8	16,196,232	.383	99.7	6,847,789	19,340,090	.354	99.5
1927	586,160	1.9	2,139,023	.274	96.5	5,859,304	19.0	15,408,831	.380	100.0	6,445,464	17,547,854	.367	99.6
1928	639,351	1.9	2,347,623	.272	96.0	5,668,493	19.4	13,474,411	.421	99.8	6,307,844	15,822,034	.399	99.4
1929	626,163	1.5	2,061,772	.304	97.5	5,826,912	18.0	12,533,470	.465	100.0	6,453,075	14,595,242	.442	99.8
1930	567,389	2.0	1,814,007	.324	99.6	5,151,089	17.5	11,062,645	.466	100.0	5,738,478	12,876,652	.446	99.6
1931	245,663	1.8	779,370	.315	85.2	3,369,481	19.7	6,146,856	.548	100.0	3,615,144	6,926,226	.522	99.0
1932	41,559	1.2	114,054	.364	75.1	1,332,975	20.8	2,845,966	.468	100.0	1,374,534	2,960,020	.464	99.2
1933	208,367	1.8	519,844	.401	93.7	1,925,090	31.0	3,965,744	.485	100.0	2,133,457	4,485,588	.476	99.4
1934	293,904	2.1	912,793	.322	80.9	2,049,915	19.4	3,726,143	.550	100.0	2,343,819	4,638,936	.505	97.6
1935	249,795	1.4	1,048,193	.238	100.0	3,027,740	24.0	4,489,974	.674	99.4	3,277,535	5,538,167	.592	99.5
1936	446,532	1.5	1,469,439	.304	77.4	3,733,435	20.8	5,558,963	.672	100.0	4,179,967	7,028,402	.595	97.6
1937	615,308	1.3	1,598,873	.386	79.9	5,692,273	23.1	8,425,800	.676	99.9	6,307,581	10,024,673	.629	98.0

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
New York, New Jersey, and Pennsylvania														
1909	745,062	3.1	n.a.	n.a.	100.0	1,467,049	5.3	n.a.	n.a.	100.0	2,212,111	n.a.	n.a.	100.0
1915	370,325	1.7	1,136,934	0.326	90.0	1,407,063	4.2	8,106,430	0.174	98.4	1,777,388	9,243,364	0.192	96.6
1916	551,503	1.6	905,199	.609	100.0	1,843,439	4.6	9,620,376	.192	97.2	2,394,942	10,525,575	.228	97.9
1917	530,095	1.5	868,485	.610	99.6	1,810,865	4.6	10,055,613	.180	96.0	2,340,960	10,924,098	.214	96.8
1918	569,814	1.6	898,033	.635	92.9	1,282,490	3.8	9,095,445	.141	99.7	1,852,304	9,993,478	.185	97.6
1919	576,786	2.0	839,347	.687	86.5	1,326,304	4.1	8,708,095	.152	94.1	1,903,090	9,547,442	.199	91.8
1920	730,643	2.2	770,314	.949	86.8	1,355,316	3.8	8,008,593	.169	98.9	2,085,959	8,778,907	.238	94.6
1921	146,649	1.1	250,144	.586	80.8	528,577	3.4	2,229,740	.237	96.6	675,226	2,479,884	.272	93.1
1922	667,751	2.7	640,721	1.042	93.7	647,825	2.9	4,335,662	.149	75.4	1,315,576	4,976,383	.264	84.7
1923	852,058	2.2	530,833	1.605	94.6	991,038	3.3	4,103,631	.242	84.4	1,843,096	4,634,464	.398	89.1
1924	616,707	2.4	782,197	.788	85.2	511,530	1.8	1,631,119	.314	67.8	1,128,237	2,413,316	.468	77.3
1925	402,107	1.3	487,383	.825	82.5	898,324	2.8	2,451,895	.366	96.1	1,300,431	2,939,278	.442	91.9
1926	717,367	2.1	704,938	1.018	86.2	1,226,104	3.7	3,889,383	.315	99.7	1,943,471	4,594,321	.423	94.7
1927	829,981	2.7	1,002,595	.828	98.4	1,414,273	4.6	4,631,111	.305	99.8	2,244,254	5,633,706	.398	99.0
1928	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	1,986,959	4,093,401	.485	99.1
1929	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	2,195,601	4,787,157	.459	98.6
1930	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	2,248,682	6,058,999	.371	99.8
1931	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	936,960	2,570,050	.365	99.9
1932	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	165,009	530,682	.311	98.7
1933	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	396,228	474,644	.835	99.7
1934	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	908,944	1,422,916	.639	99.9
1935	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	1,349,247	1,471,869	.917	100.0
1936	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	2,069,764	3,430,512	.603	100.0
1937	(e)	(e)	(e)	(e)	-	(e)	(e)	(e)	(e)	-	3,145,177	6,015,342	.523	100.0

(Footnotes at end of table.)

Table A-6.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT AND UNDERGROUND IRON MINES, BY AREA, 1909-37[a] - Continued

(Exclusive of ore containing 5 percent or more manganese)

Area and Year	Open-pit mines[b]					Underground mines[b]					All mines			
	Merchantable ore					Merchantable ore								
	Gross tons	Percent of U.S. total from open pits	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Gross tons	Percent of U.S. total from underground	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]	Merchantable ore (gross tons)	Man-hours worked[c]	Tons per man-hour	Percent of industry on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
All other areas[f]														
1909	2,087,659	8.6	n.a.	n.a.	100.0	635,055	2.3	n.a.	n.a.	100.0	2,722,714	n.a.	n.a.	100.0
1915	559,086	2.5	2,384,045	0.234	90.5	806,098	2.4	6,253,800	0.129	61.4	1,365,184	8,637,845	0.158	73.3
1916	844,696	2.4	4,835,567	.175	80.8	1,219,177	3.0	7,133,659	.171	82.1	2,063,873	11,969,226	.172	81.6
1917	1,321,723	3.7	5,357,496	.247	83.3	922,393	2.3	6,627,953	.139	88.8	2,244,116	11,985,449	.187	85.5
1918	1,163,875	3.2	5,269,618	.221	76.1	944,814	2.8	5,528,779	.171	84.1	2,108,689	10,798,397	.195	79.7
1919	820,084	2.9	2,786,805	.294	80.4	662,406	2.0	4,765,511	.139	84.5	1,482,490	7,552,316	.196	82.3
1920	854,135	2.6	3,732,598	.229	43.8	825,311	2.4	5,327,105	.155	66.8	1,679,446	9,059,703	.185	55.1
1921	200,604	1.4	453,448	.442	76.0	387,176	2.5	2,398,428	.161	79.2	587,780	2,851,876	.206	78.1
1922	326,871	1.3	823,367	.397	73.9	451,950	2.0	2,086,057	.217	80.3	778,821	2,909,424	.268	77.6
1923	529,434	1.4	1,982,785	.267	71.6	801,586	2.7	3,432,518	.234	79.7	1,331,020	5,415,303	.246	76.5
1924	535,224	2.1	1,127,411	.475	54.4	667,447	2.3	2,918,019	.229	93.4	1,202,671	4,045,430	.297	76.0
1925	615,925	2.1	1,376,839	.447	76.3	734,469	2.3	1,938,758	.379	94.2	1,350,394	3,315,597	.407	86.0
1926	652,466	1.9	1,207,566	.540	92.8	906,631	2.7	1,989,135	.456	99.9	1,559,097	3,196,701	.488	96.9
1927	671,852	2.2	1,148,855	.585	96.0	752,195	2.4	2,405,705	.313	94.6	1,424,047	3,554,560	.401	95.3
1928	1,224,376	3.7	1,708,777	.717	97.2	2,139,287	7.3	5,876,733	.364	99.1	1,376,704	3,492,109	.394	97.4
1929	1,789,405	4.4	2,004,561	.893	98.8	1,959,414	6.1	5,896,256	.332	94.7	1,553,218	3,113,660	.499	93.9
1930	1,367,233	4.7	1,141,561	1.198	98.0	1,919,568	6.5	6,404,286	.300	99.3	1,038,119	1,486,848	.698	96.6
1931	834,574	6.0	1,670,637	.500	90.1	804,368	4.7	2,314,023	.348	99.1	701,982	1,414,610	.496	87.3
1932	235,791	6.9	428,673	.550	90.0	97,164	1.5	399,609	.243	98.3	167,946	297,600	.564	86.3
1933	417,280	3.7	375,608	1.111	98.5	391,419	6.3	483,324	.810	99.8	412,471	384,288	1.073	98.6
1934	787,229	5.6	504,558	1.560	97.4	425,549	4.0	1,214,466	.350	99.8	303,834	296,108	1.026	93.1
1935	1,230,405	6.9	416,139	2.957	99.7	663,675	5.3	1,501,267	.442	100.0	544,833	445,537	1.223	99.4
1936	1,372,639	4.5	759,168	1.808	99.3	1,454,924	8.1	3,401,019	.428	99.9	757,799	729,675	1.039	98.5
1937	2,054,260	4.3	882,017	2.329	97.3	2,074,072	8.4	5,860,463	.354	100.0	983,155	727,138	1.352	94.4

[a]Includes beneficiating plants at the mines. Data for 1909 from Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept.

[d]Calculated for each year and State by dividing the total quantity of merchantable ore included in the study by the total quantity of merchantable ore produced by

[a]Includes beneficiating plants at the mines. Data for 1909 from Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), pp. 256, 258-9. Data for all other years compiled from reports of iron-mining companies to the U. S. Bureau of Mines.

[b]The reports for some of the mines which used a combination of open-pit and underground mining methods did not completely separate production and man-hours for these two branches of mining. Most of the combination mines are in Minnesota and the separation was partly estimated for this State on the basis of data in Annual Reports of Inspectors of Mines for Itasca, St. Louis, and Crow Wing Counties of Minnesota. Other estimates were based on the rates of labor productivity at open-pit and underground mines in the same mines in previous or succeeding years, or in the same year in neighboring mines, and from other clues.

[c]Man-hours were estimated for some production for which these data were not reported. The man-hour estimates were made by dividing production for which employment data were lacking, by the tons per man-hour for the mines for which employment data were reported and which were located in the same area and used the same mining method.

[d]Calculated for each year and State by dividing the total quantity of merchantable ore included in the study by the total quantity of merchantable ore produced by each mining method. Merchantable ore included in the study is that ore for which employment data were reported and from which tons-per-man ratios were computed.

[e]Not at liberty to publish data separately; so they have been included with "All other areas."

[f]Includes California, Colorado, Connecticut, Georgia, Idaho, Iowa, Maryland, Massachusetts, Mississippi, Missouri, Montana, Nevada, New Mexico, North Carolina, Ohio, Tennessee, Utah, Virginia, Washington, and Wyoming. In addition, data for open-pit and underground mining separately for 1928-37, include New York, New Jersey, and Pennsylvania. Some of the States included are regular producers, while others produce sporadically.

[g]Preliminary.

n.a. Data not available.

Table A-7.- IRON ORE PRODUCED IN THE UNITED STATES FROM MINES CLASSIFIED BY OUTPUT PER MAN-HOUR, 1937[a]

Average output of merchantable ore per man-hour (Gross tons)	Producing mines		Merchantable ore produced										
			Gross tons					Percent of United States production					Percent of total production from mines with designated productivity that was -
	Number	Average output per mine (gross tons)	Total	From open pits	From underground	Concentrated ore	Direct-shipping ore[b]	Total	From open pits	From underground	Concentrated ore	Direct-shipping ore[b]	From open pits	Direct-shipping ore[b]
(Class interval of 0.10)														
0.0 - 0.09	2	366	732	-	732	732	-	(c)	-	(c)	(c)	-	-	-
0.1 - 0.19	17[d]	797[d]	13,543	9,369	4,174	-	13,543	(c)	(c)	(e)	-	(c)	69.2	100.0
0.2 - 0.29	32[d]	44,043[d]	1,409,371	195,001	1,214,370	1,303,330	106,041	2.0	0.4	4.9	11.3	0.2	13.8	7.5
0.3 - 0.39	16[d]	45,221[d]	723,537	154,509	569,028	281,385	442,152	1.0	0.3	2.4	2.4	0.7	21.4	61.1
0.4 - 0.49	10	30,830	308,301	304,796	3,505	271,708	36,593	0.4	0.6	(c)	2.4	0.1	98.9	11.9
0.5 - 0.59	11	258,660	2,845,257	37,934	2,807,323	98,449	2,746,808	3.9	0.1	11.4	0.9	4.5	1.3	96.5
0.6 - 0.69	17	269,371	4,579,313	110,745	4,468,568	100,907	4,478,406	6.4	0.2	18.1	0.9	7.4	2.4	97.8
0.7 - 0.79	8	389,443	3,115,543	99,491	3,016,052	-	3,115,543	4.3	0.2	12.2	-	5.1	3.2	100.0
0.8 - 0.89	9	380,176	3,421,585	35,765	3,385,820	56,301	3,365,284	4.7	0.1	13.7	0.5	5.6	1.0	98.4
0.9 - 0.99	14	389,239	5,449,342	454,320	4,995,022	528,451	4,920,891	7.6	1.0	20.3	4.6	8.1	8.3	90.3
(Class interval of 0.50)														
1.0 - 1.49	15	277,282	4,159,237	2,332,597	1,826,640	573,024	3,586,213	5.8	4.9	7.4	5.0	5.9	56.1	86.2
1.5 - 1.99	25	275,048	6,876,208	4,820,302	2,055,906	2,840,572	4,035,636	9.5	10.2	8.4	24.7	6.7	70.1	58.7
2.0 - 2.49	4	346,268	1,385,070	1,385,070	-	980,341	404,729	1.9	2.9	-	8.5	0.7	100.0	29.2
2.5 - 2.99	8	650,772	5,206,179	5,206,179	-	2,403,508	2,802,671	7.2	11.0	-	20.9	4.6	100.0	53.8
(Class interval of 2.00)														
3.0 - 4.99	10	611,834	6,118,336	6,118,336	-	2,068,967	4,049,369	8.5	12.9	-	17.9	6.7	100.0	66.2
5.0 - 6.99	6	992,795	5,956,770	5,661,463	295,307[e]	-	5,956,770	8.3	11.9	1.2[e]	-	9.8	95.0	100.0
7.0 - 8.99	3	5,109,661	15,328,984	15,328,984	-	-	15,328,984	21.3	32.3	-	-	25.3	100.0	100.0
9.0 - 10.99	2	2,598,120	5,196,240	5,196,240	-	-	5,196,240	7.2	11.0	-	-	8.6	100.0	100.0
United States total	209[d]	344,945[d]	72,093,548	47,451,101	24,642,447	11,507,675	60,585,873	100.0	100.0	100.0	100.0	100.0	65.8	84.0

[a]Based on reports of iron-mining companies to the U. S. Bureau of Mines. In a few instances data did not permit the segregation of production and employment for individual mines. In such cases the productivity of the group of two or more mines combined was used; the production of 23 such groups, including 55 mines, amounted to 10.7 percent of the total.

[b]Represents ore that did not require concentration before shipment and includes ore that was simply crushed or screened.

[c]Less than 0.1 percent.

[d]Exclusive of an undetermined number of small open-pit operations in Alabama, Georgia, and Missouri. The output of these pits, aggregating 49,611 gross tons, is included in the total production for the United States.

[e]Represents production from the underground portion of a mine that employed a combination of open-pit and underground mining methods.

Table A-8.- IRON ORE MINED AND CONCENTRATED AT MINES, WASTE REMOVED IN CONCENTRATING, AND MERCHANTABLE ORE PRODUCED IN THE UNITED STATES, 1909-37[a]

	Merchantable ore produced

Table A-8.- IRON ORE MINED AND CONCENTRATED AT MINES, WASTE REMOVED IN CONCENTRATING, AND MERCHANTABLE ORE PRODUCED IN THE UNITED STATES, 1909-37[a]

Year	Total ore mined (partly estimated)[b]	Crude ore sent to concentrators (partly estimated)[b]	Merchantable ore produced						Waste removed in concentrating (gross tons)
			Concentrates recovered[c]		Direct-shipping ore (gross tons)	Total merchantable ore			
						Gross tons	Iron (natural) contained		
	Gross tons	Gross tons	Gross tons	Percent of total merchantable ore			Gross tons	Percent	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				(3)÷(6)		(5)+(5)		(7)÷(6)	(2)-(3)
1909	51,947,129	882,548	653,339	1.3	51,064,581	51,717,920	n.a.	n.a.	229,209
1914	45,768,000	8,313,000	3,986,334	9.6	37,454,427	41,439,761	n.a.	n.a.	4,328,000
1915	60,882,000	10,753,000	5,397,754	9.7	50,128,736	55,526,490	n.a.	n.a.	5,355,000
1916	82,161,000	14,530,000	7,536,830	10.0	67,630,842	75,167,672	n.a.	n.a.	6,993,000
1917	82,869,000	15,098,000	7,517,953	10.0	67,770,898	75,288,851	n.a.	n.a.	7,580,000
1918	77,447,000	15,692,000	7,903,500	11.5	61,754,978	69,658,278	n.a.	n.a.	7,789,000
1919	67,612,000	13,671,000	7,024,296	11.5	55,941,122	60,965,418	n.a.	n.a.	6,646,000
1920	75,514,000	15,452,000	7,522,850	11.1	60,081,655	67,604,465	n.a.	n.a.	7,909,000
1921	33,246,000	7,649,000	3,893,680	13.2	25,597,298	29,490,978	n.a.	n.a.	3,755,000
1922	53,736,000	12,593,000	5,985,097	12.7	41,145,430	47,128,527	n.a.	n.a.	6,607,000
1923	80,669,623	21,230,000	9,911,600	14.3	59,439,842	69,351,442	34,970,461	50.42	11,318,000
1924	61,458,841	15,781,000	6,589,894	12.1	47,677,525	54,267,419	27,082,183	49.91	7,191,000
1925	70,474,965	16,516,000	7,949,515	12.8	53,958,682	61,907,997	31,090,824	50.22	8,567,000
1926	75,943,775	16,089,000	7,768,099	11.5	59,854,901	67,623,000	34,099,262	50.43	8,321,000
1927	69,923,057	15,470,000	7,288,176	11.8	54,452,924	61,741,100	30,879,989	50.02	8,182,000
1928	70,940,916	16,454,000	7,690,607	12.4	54,506,481	62,197,088	31,149,584	50.08	8,744,000
1929	85,164,881	18,849,000	8,711,646	11.9	64,316,074	73,027,720	36,637,660	50.17	10,137,000
1930	68,551,913	18,659,000	8,518,461	14.6	49,893,203	58,408,664	29,565,457	50.28	10,145,000
1931	35,563,894	8,958,000	4,505,731	14.5	26,625,771	31,131,502	15,624,850	50.19	4,432,000
1932	11,181,678	2,875,000	1,540,603	15.6	8,306,313	9,846,916	4,948,245	50.25	1,335,000
1933	21,225,858	6,656,000	2,982,922	17.0	14,570,266	17,553,188	8,777,574	50.01	5,675,000
1934	28,252,896	7,311,000	3,645,624	14.8	20,941,992	24,587,616	12,384,257	50.37	5,665,000
1935	35,567,816	10,311,000	5,485,841	18.0	25,056,411	30,540,252	15,361,718	50.30	4,828,000
1936	54,856,497	14,204,000	8,136,445	16.7	40,652,302	48,788,745	24,684,271	50.59	6,068,000
1937	80,906,084	20,320,000	11,507,675	16.0	60,585,873	72,093,548	36,410,611	50.50	8,815,000

[a]Data for 1914-37 are exclusive of ore containing 5 percent or more manganese. Data for 1909 from Thirteenth Census of the United States: 1910, Vol. XI,"Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), pp. 258-9; for all other years, data are based on reports of iron-mining companies to the U. S. Bureau of Mines.

[b]Crude ore mined and crude sent to concentrators were partly estimated. Data for 1914-22 involved more estimates than for subsequent years. Most of the estimates are of iron-bearing material produced at most brown-ore mines, as only the cleaned ore is weighed at these mines. The ratio of ore-bearing material, or dirt, varies not only from one deposit to another, but also from place to place in the same deposit. From data available, it is apparent that the ratio of ore-bearing material, or dirt, to cleaned ore ranges from 2 cubic yards to 1 ton in the richer deposits, to about 12 cubic yards to 1 ton at the poorer deposits. The quantity of brown ore mined annually is comparatively small, and averaged 1.3 percent annually during the 1923-32 period, so that even a major error in calculations would not seriously impair the value of the principal trends shown by the figures. See O. E. Kiessling and H. W. Davis, "Iron Ore, Pig Iron, Ferro-Alloys, and Steel," Minerals Yearbook, 1934 (U. S. Dept. Int., Bur. Mines, 1934), p. 326.

[c]Includes concentrates recovered by all methods of ore treatment whereby the proportion of metallic iron in the ore is increased by removing waste materials and moisture. Excludes ore beneficiated by simple processes of screening and crushing that only improve the physical character of the ore.

n.a. Data not available.

Table A-9.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT CONCENTRATING AND NONCONCENTRATING OPEN-PIT MINES IN MINNESOTA, 1923-37[a]

Year	Mines that concentrated ore[b]						Mines that did not concentrate ore[b c]			All open-pit mines[d]					
	Crude sent to concentrators (Gross tons)	Merchantable ore produced (Gross tons)			Man-hours worked	Tons of merchantable ore per man-hour	Merchantable ore produced (Gross tons)	Man-hours worked	Tons per man-hour	Merchantable ore produced (Gross tons)			Man-hours worked	Tons per man-hour	Percent of open-pit production on which based[b e]
		Concentrates recovered	Direct-shipping ore	Total						From mines using open-pit methods only	From open pits of combination mines (partly estimated)	Total			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
				(2)+(3)		(4)÷(5)			(7)÷(8)	(4)+(7)		(10)+(11)		(12)÷(13)	
1923	10,693,115	6,802,391	1,384,401	8,186,792	8,159,462	1.003	22,563,973	13,987,017	1.613	30,750,765	4,548,286	35,299,051	25,351,971	1.392	97.7
1924	7,231,554	4,800,246	1,631,074	6,431,320	7,902,614	.814	13,226,808	8,933,428	1.481	19,658,128	2,954,229	22,612,357	19,919,562	1.135	98.9
1925	8,602,200	5,656,091	1,202,034	6,858,125	4,455,395	1.539	16,033,744	6,603,372	2.428	22,891,869	3,619,847	26,511,716	15,686,480	1.690	98.3
1926	6,636,903	4,099,982	1,663,421	5,763,403	3,880,539	1.485	18,884,081	4,738,904	3.985	24,647,484	5,844,360	30,491,844	13,141,691	2.320	97.4
1927	7,224,687	4,450,934	1,030,276	5,481,209	4,447,852	1.232	15,796,965	6,067,204	2.604	21,278,174	5,482,724	26,760,898	14,390,510	1.860	96.4
1928	8,969,662	5,435,929	488,719	5,924,648	4,214,440	1.406	17,899,736	5,966,003	3.000	23,824,384	5,321,551	29,145,935	13,417,295	2.172	94.7
1929	10,412,324	5,981,661	1,718,980	7,700,641	6,687,490	1.151	23,093,343	7,474,296	3.090	30,793,984	5,354,874	36,148,858	17,034,444	2.122	97.7
1930	10,626,852	5,934,987	937,260	6,872,247	6,291,371	1.092	15,859,484	6,815,466	2.327	22,731,731	2,790,481	25,522,212	15,401,770	1.657	98.8
1931	5,869,471	3,571,233	358,941	3,930,174	3,610,630	1.089	7,538,779	4,465,986	1.688	11,468,953	586,359	12,055,312	8,529,431	1.413	99.5
1932	2,461,954	1,444,681	655,795	2,100,476	831,207	2.527	821,008	2,036,490	.403	2,921,484	-	2,921,484	2,961,667	.986	91.1
1933	4,571,440	2,589,528	329,155	2,918,683	1,982,252	1.472	6,162,699	1,981,763	3.110	9,081,382	1,324,327	10,405,709	4,583,625	2.270	99.3
1934	4,551,546	2,799,108	100,407	2,899,515	2,272,674	1.276	8,237,493	3,272,672	2.517	11,137,008	1,171,101	12,308,109	6,193,801	1.987	95.5
1935	7,732,835	4,310,683	1,386,373	5,697,056	3,306,585	1.723	9,400,770	1,946,540	4.829	15,097,826	642,128	15,739,954	5,550,675	2.836	100.0
1936	10,506,578	6,412,982	1,627,399	8,040,381	3,524,626	2.281	17,984,411	5,125,650	3.509	26,024,792	1,323,683	27,348,475	8,926,364	3.064	100.0
1937	14,884,794	8,926,291	2,094,666	11,020,957	4,888,911	2.254	28,644,385	6,958,759	4.116	39,665,342	3,069,210	42,734,552	12,650,727	3.378	99.6
1923-37	120,974,715	73,216,727	16,608,900	89,825,627	66,456,048	1.352	222,147,679	86,575,540	2.572	311,973,306	44,033,160	356,006,466	183,739,813	1.938	98.2

[a]Data from reports of iron-mining companies to the U. S. Bureau of Mines.

[b]Exclusive of open-pit operations worked in conjunction with underground mining.

[c]Includes mines which concentrated all or part of the crude ore mined by removing waste materials or moisture; but excludes mines which beneficiated their ores by simple methods of crushing or screening.

[d]The reports for a few mines which used a combination of open-pit and underground mining methods did not completely separate production and man-hours for these two branches of mining. The separation was partly estimated on the basis of data in Annual Reports of Inspectors of Mines for Itasca, St. Louis, and Crow Wing Counties. Other estimates were based on the rates of labor productivity at the same mines in previous or succeeding years or in the same year in neighboring mines, and from other clues.

[e]Calculated for each year by dividing the total quantity of merchantable ore included in the study by the total quantity of merchantable ore produced. Merchantable ore included in the study is that ore for which employment data were reported and from which tons-per-man ratios were computed.

Table A-10.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT CONCENTRATING AND NONCONCENTRATING OPEN-PIT AND UNDERGROUND MINES IN THE UNITED STATES, 1936 AND 1937[a]

Table A-10.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT CONCENTRATING AND NONCONCENTRATING OPEN-PIT AND UNDERGROUND MINES IN THE UNITED STATES, 1936 AND 1937[a]

State and type of mine	Mines that did not concentrate ore					Mines that concentrated ore[b]						All mines				
	Merchantable ore produced					Merchantable ore produced						Merchantable ore produced				
						Concentrated ore	Total merchantable ore									
	Gross tons	Percent of State total by designated mining method	Man-hours worked[c]	Tons per man-hour	Percent of output of mines in this class on which based[d]	(Gross tons)	Gross tons	Percent of State total by designated mining method	Man-hours worked[c]	Tons per man-hour	Percent of output of mines in this class on which based[d]	Gross tons	Percent of United States total by designated mining method	Man-hours worked[c]	Tons per man-hour	Percent of output of mines in this class on which based[d]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Open-pit																
Minnesota	50,074,788	71.5	12,794,103	3.914	99.9	15,619,883	20,008,239	28.5	8,782,988	2.278	99.4	70,083,027	58.0	21,577,091	3.248	99.8
Michigan	3,685,768	100.0	1,104,417	3.337	100.0	-	-	-	-	-	-	3,685,768	3.0	1,104,417	3.337	100.0
Alabama	175,570	16.5	746,727	.235	4.6	886,270	886,270	83.5	2,321,585	.382	93.5	1,061,840	.9	3,068,312	.346	78.8
All other States	3,375,597	98.5	1,400,285	2.411	98.2	51,302	51,302	1.5	240,900	.213	53.8	3,426,899	2.8	1,641,185	2.088	98.1
United States	57,311,723	73.2	16,045,532	3.572	99.6	16,557,455	20,945,811	26.8	11,345,473	1.846	99.0	78,257,534	64.7	27,391,005	2.857	99.4
Underground																
Minnesota	8,672,308	87.0	10,474,070	.828	100.0	715,062	1,295,714	13.0	1,604,687	.807	99.2	9,968,022	8.3	12,078,757	.826	99.9
Michigan and Wisconsin	19,702,033	100.0	25,946,769	.759	100.0	-	-	-	-	-	-	19,702,033	16.3	25,946,769	.759	100.0
Alabama	9,425,708	100.0	13,984,763	.674	100.0	-	-	-	-	-	-	9,425,708	7.8	13,984,763	.674	100.0
All other States	1,187,395	32.8	1,419,930	.815	99.0	2,371,601	2,371,601	67.2	7,841,552	.302	100.0	3,528,996	2.9	9,261,482	.381	100.0
United States	38,957,444	91.4	51,825,532	.752	100.0	3,086,663	3,667,315	8.6	9,446,239	.388	99.7	42,624,759	35.3	61,271,771	.696	99.9

[a]Data from reports of iron-mining companies to the U. S. Bureau of Mines. The apportionment of production and man-hours was partly estimated for a few mines that reported a combination of underground and open-pit methods of mining.

[b]Includes data for a few mines which produced some ore that was not concentrated; the amount of this direct-shipping ore may be derived by subtracting col. (6) from col. (7).

[c]Includes man-hours worked at beneficiating plants.

[d]Calculated for each year by dividing the quantity of merchantable ore covered in the study by the total quantity of merchantable ore produced. Merchantable ore covered in the study is that ore for which employment data were reported, and from which tons-per-man ratios were computed.

Table A-11.- THE TREND TOWARD CONCENTRATION OF IRON-ORE PRODUCTION AT LARGER MINES IN THE UNITED STATES, 1880-1937[a]

Year	Merchantable ore produced (thousands of gross tons)	Number of producing mines	Average number of days worked	Average output per mine (gross tons)		Percent of total output from mines with the designated annual production[b] (thousands of gross tons)				
				Per year	Per day	Less than 50	50 to 200	200 to 500	500 to 1,000	Over 1,000
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1880[b]	6,308	805[c]	233	7,836	34	65.2	27.7	7.1	-	-
1889	14,518	592[d]	247	24,524	99	28.4	33.6	20.6	17.4	-
1900	27,553	n.a.	n.a.	n.a.	n.a.	11.7	26.8	22.8	25.4	13.3
1901	28,887	n.a.	n.a.	n.a.	n.a.	11.6	n.a.	n.a.	n.a.	n.a.
1902	35,554	525	260	67,722	260	11.2	21.8	20.?	21.8	25.0
1903	35,019	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1904	27,644	n.a.	n.a.	n.a.	n.a.	9.6	28.0	26.0	16.8	19.7
1905	42,526	n.a.	n.a.	n.a.	n.a.	7.5	18.6	29.4	12.6	31.9
1906	47,750	449	n.a.	106,347	n.a.	8.9	20.5	26.1	13.3	31.3
1907	51,721	479	n.a.	107,977	n.a.	7.0	21.4	24.2	13.7	33.7
1908	35,983	407	n.a.	88,410	n.a.	8.1	26.4	30.9	13.4	21.2
1909	51,718	483	n.a.	107,077	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1910	57,015	451	n.a.	126,419	n.a.	6.1	20.1	22.1	17.9	33.8
1911	43,877	374	n.a.	117,318	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1912	55,150	382	n.a.	144,372	n.a.	5.0	17.4	25.7	18.2	33.7
1913	61,980	411	n.a.	150,803	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1914	41,440	340	n.a.	121,882	n.a.	6.0	25.6	29.1	22.3	17.0
1915	55,526	340	272	163,312	600	3.5	19.9	26.3	27.4	22.9
1916	75,168	405	274	185,600	677	3.4	16.1	27.5	16.4	36.6
1917	75,289	452	280	166,569	595	n.a.	n.a.	n.a.	n.a.	n.a.
1918	69,658	458	293	152,092	519	4.2	20.2	22.1	20.9	32.6
1919	60,965	389	280	156,722	560	n.a.	n.a.	n.a.	n.a.	n.a.
1920	67,604	403	287	167,752	585	n.a.	n.a.	n.a.	n.a.	n.a.
1921	29,491	256	209	115,199	551	7.4	24.5	28.8	6.6	32.7
1922	47,129	293	250	160,850	643	4.3	19.6	26.7	18.4	31.0
1923	69,351	309	286	224,437	785	2.7	14.3	27.1	18.8	37.1
1924	54,267	260	263	208,719	794	3.8	15.4	26.6	17.6	36.6
1925	61,908	238	270	260,118	963	1.9	11.9	33.1	15.8	37.3
1926	67,623	233	273	290,227	1,063	1.6	12.1	28.8	17.8	40.6
1927	61,741	232	264	266,125	1,008	1.5	13.3	31.7	18.4	35.0
1928	62,197	211	265	294,773	1,112	1.5	12.8	28.9	21.2	35.7
1929	73,028	211	281	346,104	1,232	0.9	9.1	27.6	16.6	45.8
1930	58,409	208	259	280,812	1,084	1.1	16.1	29.9	16.8	36.0
1931	31,132	186[e]	201	167,132[e]	832	4.2	21.5	32.3	23.7	18.3
1932	9,847	129[e]	145	76,257[e]	526	n.a.	n.a.	n.a.	n.a.	n.a.
1933	17,553	132	140	132,977	950	4.3	30.5	24.4	22.3	18.6
1934	24,588	141	193	174,383	904	2.5	29.8	24.7	19.8	23.2
1935	30,540	142	219	215,070	982	n.a.	n.a.	n.a.	n.a.	n.a.
1936	48,789	196	227	248,923	1,097	1.6	9.5	22.3	22.0	44.6
1937	72,094	205[e f]	247	351,434[e]	1,423	1.4	7.1	17.0	24.3	50.2

[a]Production represents merchantable iron ore. Data for 1880 from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), p. 64; for 1889 from Eleventh Census of the United States: 1890, "Report on Mineral Industries" (1892), p. 4; for 1909 from Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), p. 242; for all other years from reports of iron-mining companies to the U. S. Bureau of Mines.

[b]Some of the reports for mines producing more than 50,000 tons lumped the production of two or more mines, and this production, amounting to from 1 to 10 percent of the total output, was distributed among the mines of the designated sizes in the same proportion as for those mines whose annual production was known.

[c]Exclusive of 1,325 irregular producers in 1880 with a total production of 812,479 gross tons; 1,125 of these produced less than 300 tons each.

[d]Eighty-one of these mines in 1889 produced less than 300 tons each.

[e]Exclusive of an undetermined number of small open-pit operations which produced an aggregate of 44,994 gross tons in 1931, 9,759 gross tons in 1932, and 49,611 gross tons in 1937. The production from these pits was included in the computations of percent of total output from mines with an annual production of less than 50,000 gross tons.

[f]The total number of mines here presented is four less than the number shown in table A-7 because two groups of mines were each counted as one mine although embracing six mines. This method of counting certain groups as individual mines was followed consistently for the purpose of this table (although in some years it was possible to make a more logical segregation) in order not to distort the trend in average size of mines by a change in the method of counting mines.

n.a. Data not available.

Table A-12.- GROWTH IN THE USE OF POWER EQUIPMENT AT PRODUCING IRON MINES IN THE UNITED STATES, 1880-1929[a]

State and year	Average number of wage earners[b]	Rated horsepower of prime movers and electric motors using purchased energy		Rated horsepower of prime movers		Rated horsepower of electric motors	
		Total	Per wage earner	Steam engines and turbines[c]	All other[d]	Using purchased energy	Using energy generated at mines
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
United States							
1880[e]	50,415	28,422[f]	0.9	28,422[f]	-	-	-
1889[g]	36,541	57,976[h]	1.6	57,976[h]	-	-	-
1902	44,800[i]	119,558	2.7[j]	118,462	1,096	-	937
1909	52,250	546,534	6.6	326,753	15,316	4,465	13,295
1919	51,780	370,869	7.2	259,705	15,782	97,382	67,595
1929	30,765	498,821	16.2	204,249	17,905	276,667	40,688
Minnesota							
1880[e]	-	-	-	-	-	-	-
1889	1,697	1,610[h]	0.9	1,610[h]	-	-	-
1902	(k)	25,532	(k)	25,322	10	-	375
1909	16,218	145,068	8.9	145,010	58	-	4,338
1919	16,815	135,924	8.1	110,059	772	25,093	15,565
1929	11,514	184,042	16.0	105,063	1,606	79,375	5,594
Michigan & Wisconsin							
1880[e]	5,413	6,259[f]	1.2	6,259[f]	-	-	-
1889	14,253	27,145[h]	1.9	27,145[h]	-	-	-
1902	(k)	55,289	(k)	52,539	750	-	388
1909	17,580	117,402	6.7	104,976	12,261	165	7,349
1919	18,880	149,291	7.9	89,389	8,274	51,628	40,957
1929	10,297	190,460	18.5	64,843	13,910	111,707	27,294
Alabama							
1880[e]	719	192[f]	0.3	192[f]	-	-	-
1889	3,019	1,971[h]	0.7	1,971[h]	-	-	-
1902	(k)	10,370	(k)	10,370	-	-	-
1909	5,666	31,838	5.6	31,838	-	-	50
1919	8,548	36,890	4.4	28,690	30	8,170	4,614
1929	5,498	61,442	11.2	25,150	40	58,272	5,907
N.Y., N.J., & Penn.							
1880[e]	17,517	20,052[f]	1.1	20,052[f]	-	-	-
1889	9,010	19,681[h]	2.2	19,681[h]	-	-	-
1902	(k)	17,179	(k)	17,051	148	-	54
1909	5,365	33,076	6.2	26,065	2,711	4,300	1,491
1919	4,163	(l)	(l)	(l)	(l)	(l)	(l)
1929	2,097	49,660	23.7	10,250	157	39,253	2,040
All other States							
1880[e]	6,765	1,919[f]	0.3	1,919[f]	-	-	-
1889	8,582	7,569[h]	0.9	7,569[h]	-	-	-
1902	(k)	13,388	(k)	13,200	188	-	120
1909	7,403	19,150	2.6	18,864	286	-	67
1919	3,574	48,764[m]	13.6[m]	31,567[m]	4,706[m]	12,491[m]	8,461[m]
1929	1,357	13,217	9.7	2,963	2,192	8,062	1,953

[a]Data are from Tenth Census of the United States: 1880, Vol. XV, "Report on the Mining Industries" (U. S. Dept. Int., Census Office, 1886), pp. 65-6; Eleventh Census of the United States: 1890, "Report on Mineral Industries" (1892), pp. 17-8, 21; Special Reports of the Census Office, "Mines and Quarries: 1902" (U. S. Dept. Com. and Labor, Bur. Census, 1906), pp. 426, 430-1; Thirteenth Census of the United States: 1910, Vol. XI, "Mines and Quarries: 1909" (U. S. Dept. Com., Bur. Census, 1913), pp. 258-9; Fourteenth Census of the United States: 1920, Vol. XI, "Mines and Quarries: 1919" (1922), p. 350; Fifteenth Census of the United States: 1930, "Mines and Quarries: 1929" (1933), pp. 326-7.

[b]Data were selected for comparability as nearly as possible and represent approximately the average number of wage earners in active payroll periods. This differs from the number used by the Bureau of the Census in 1902, 1909, 1919, and 1929. The Bureau of the Census computed the average number of wage earners for these years by adding the numbers on the payrolls for each month and dividing the sum by 12, regardless of whether or not the mines were idle during one or more of the 12 months. Since the use of census data for these years would have understated the typical number of employees when mines are in operation, employment data as reported to the Bureau of Mines for 1919 and 1929 were used in place of data compiled by the Census Bureau. The Bureau of Mines did not collect data on wage earners in 1909. The number presented in the table is taken from the 1909 Census and represents the number of wage earners reported for all producing mines on a representative day.

[c]The use of steam turbines was first reported in the Census of 1919. None were in use in the previous censuses.

[d]Includes internal-combustion engines, water wheels, water turbines, and other power equipment not elsewhere specified.

[e]Data are for regular producing establishments only. Small irregular establishments which produced about 11 percent of the total output of iron ore in the United States were excluded. In addition to the mechanical equipment enumerated herein the Census of 1880 reported the use of 1,249 mules and 2,744 horses in all the regular iron-mining establishments in the United States.

[f]Represents horsepower rating of steam boilers. These boilers supplied power to 821 steam engines in all regular iron-mining establishments in the United States. The rated horsepower of these steam engines was 24,838, or about 87 percent of the total horsepower of steam boilers.

[g]In addition, a total of 2,796 mules and horses were in use in all iron mines in the United States.

[h]Data represent the aggregate horsepower rating of steam boilers. The horsepower rating of steam engines is lower than that of steam boilers. For the United States as a whole data exclude the motive power for 79 pumps, 20 locomotives, 4 steam shovels, 8 turbine wheels, and 10 compressors worked by water power. It is believed that the exclusion of the horsepower rating of this equipment is offset by the inclusion of the horsepower rating of steam boilers rather than of steam engines as for all subsequent years.

[i]The number of wage earners in the United States in 1902 was estimated from data on man-shifts worked by estimating an average of 260 shifts per man. Data as reported by the Census were not comparable since the number of wage earners (38,851) represented the number that would have been required at continuous employment of 300 days per year to produce the product of that year. Iron mines do not average 300 days per year; hence the number of employees as reported by the Census was lower than the typical number in periods when mines were in operation.

[j]See footnote i.

[k]Comparable data not available.

[l]Data for 1919 did not permit the segregation of these States; they are included in "All other States."

[m]Includes New York, New Jersey, and Pennsylvania which are shown separately in other years.

Table A-13.- ELECTRICITY SOLD TO IRON-MINING COMPANIES AND IRON ORE PRODUCED IN THE LAKE SUPERIOR DISTRICT, 1921-37

(Includes mines producing manganiferous iron ore)

Year	Electricity sold to iron-mining companies[a] (Kilowatt-hours)			Merchantable ore produced[b] (Gross tons)			Kilowatt-hours of electricity sold per ton of ore produced		
	Minnesota	Michigan and Wisconsin	Lake Superior District	Minnesota	Michigan and Wisconsin	Lake Superior District	Minnesota	Michigan and Wisconsin	Lake Superior District
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1921	24,605,848	n.a.	n.a.	17,867,855	7,540,506	25,408,361	1.38	n.a.	n.a.
1922	30,871,316	n.a.	n.a.	29,322,613	11,043,106	40,365,719	1.05	n.a.	n.a.
1923	48,842,633	89,596,121[c]	138,438,754[c]	45,101,111	15,623,709	60,724,820	1.08	5.73[c]	2.28[c]
1924	51,883,325	94,887,130[c]	146,770,455[c]	32,423,527	13,306,624	45,730,151	1.60	7.13[c]	3.21[c]
1925	57,749,770	102,706,758[c]	160,456,528[c]	37,675,318	15,810,445	53,485,763	1.53	6.50[c]	3.00[c]
1926	62,064,717	106,047,375	168,112,092	41,659,830	16,678,232	58,338,062	1.49	6.36	2.88
1927	69,899,765	120,160,479	190,060,244	36,402,013	16,525,406	52,927,419	1.92	7.27	3.59
1928	80,293,498	118,219,044	198,512,542	38,592,506	15,010,780	53,603,286	2.08	7.88	3.70
1929	96,166,024[d]	116,614,103[d]	212,780,127[d]	46,765,278	17,103,057	63,868,335	2.06	6.82	3.33
1930	102,051,460	129,532,473	231,583,933	35,211,294	14,865,637	50,076,931	2.90	8.71	4.62
1931	75,039,509	92,866,161	167,905,670	17,662,355	8,432,413	26,094,768	4.25	11.01	6.43
1932	44,513,868	64,984,571	109,498,439	5,154,291	2,994,718	8,149,009	8.64	21.70	13.44
1933	42,861,363	56,877,328	99,738,691	12,120,318	2,668,881	14,789,199	3.54	21.31	6.74
1934	55,259,474	71,009,271	126,268,745	15,587,492	5,642,087	21,229,579	3.55	12.59	5.95
1935	66,465,621	76,593,697	143,059,318	19,793,996	6,005,478	25,799,474	3.36	12.75	5.54
1936	90,417,455	96,452,203	186,869,658	32,474,789	10,147,556	42,622,345	2.78	9.50	4.38
1937	110,710,700	121,248,868	231,959,568	49,590,622	13,250,389	62,841,011	2.23	9.16	3.69

[a]From reports of electric-power companies to the U. S. Bureau of Mines.

[b]From reports of iron-mining companies to the U. S. Bureau of Mines. Data include merchantable iron ore produced and the shipments of relatively small quantities of manganiferous iron ore.

[c]The sales of electricity by two of the four electric-power companies supplying iron mines in Michigan and Wisconsin were partly estimated.

[d]These data differ a little from the reports of iron-mining companies to the Bureau of the Census on the quantities of purchased energy consumed in 1929. (See table A-14.) The sales of electricity to iron-mining companies as reported to the Bureau of Mines by electric-power companies exclude sales of electricity, for lighting purposes only, by municipal companies. On the other hand, data on sales to iron-mining companies reported to the Bureau of Mines may include small quantities of electricity used at establishments other than mines, beneficiating plants, and auxiliary works.

Table A-14.- CONSUMPTION OF ELECTRICITY AT IRON MINES AND BENEFICIATING PLANTS IN THE UNITED STATES, BY STATE, 1929[a]

(Includes some mines producing manganiferous ore)

Table A-14.- CONSUMPTION OF ELECTRICITY AT IRON MINES AND BENEFICIATING PLANTS IN THE UNITED STATES, BY STATE, 1929[a]

(Includes some mines producing manganiferous ore)

State or district	Merchantable ore produced (Gross tons)	Kilowatt-hours of electricity consumed				Kilowatt-hours consumed per ton of ore produced			Horsepower of electric motors	
		Purchased		Generated by reporting enterprises	Total	Purchased electricity	Electricity generated by reporting enterprises	Total	Run by purchased energy	Run by energy generated by reporting enterprises
		Total	Percent of total							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Minnesota	46,815,208	90,080,241	95.4	4,365,538	94,445,779	1.9	0.1	2.0	79,373	3,594
Michigan	15,238,409	125,198,225	67.2	61,004,223	186,202,448	8.2	4.0	12.2	98,274	27,294
Wisconsin	1,618,103	13,801,827	100.0	-	13,801,827	8.5	-	8.5	13,433	-
Total, Lake Superior District	63,671,720	229,080,293	77.8	65,369,761	294,450,054	3.6	1.0	4.6	191,080	30,888
Pennsylvania	1,093,133	40,216,707	100.0	-	40,216,707	36.8	-	36.8	16,441	-
New York	825,545	22,652,619	90.4	2,413,600	25,066,219	27.5	2.9	30.4	16,471	1,320
New Jersey	281,331	6,471,660	91.9	572,440	7,044,100	23.0	2.0	25.0	6,341	720
Total, Northeastern District	2,198,007	69,340,986	95.9	2,986,040	72,327,026	31.5	1.4	32.9	39,253	2,040
Alabama	6,424,478	66,721,757	70.9	27,376,500	94,098,257	10.4	4.3	14.7	38,272	5,807
All other States	1,669,280	10,492,982	72.4	4,002,937	14,495,919	6.3	2.4	8.7	8,062	1,955
Total, United States	73,965,485	375,636,018	79.0	99,735,238	475,371,256	5.1	1.3	6.4	276,667	40,688

[a]Data from Fifteenth Census of the United States: 1930, "Mines and Quarries: 1929" (U. S. Dept. Com., Bur. Census, 1933), pp. 326-7.

Table A-15.- NUMBER OF EMPLOYEES AT OPEN-PIT IRON MINES IN MINNESOTA AND ALABAMA IN 1924 AND 1931, BY OCCUPATION[a]

(Data are for 17 mines in 1924 and 19 mines in 1931)

Occupation	Number of employees for a pay period in -		Percent of total employees for a pay period in -	
	Aug.-Oct. 1924[b]	June-Oct. 1931[c]	Aug.-Oct. 1924[b]	June-Oct. 1931[c]
Primarily operating functions, total	1,800	1,230	53.3	45.6
Drilling and blasting, total	192	184	5.7	6.8
Drilling machine operators and helpers	166	139	4.9	5.1
Shot firers or dobie men	26	19	0.8	0.7
Hand drillers	-	26	-	1.0
Loading (power shovel operation), total	630	259	18.7	9.6
Pitmen	341	116	10.1	4.3
Shovel engineers	88	60	2.6	2.2
Shovel firemen	127	51	3.8	1.9
Shovel cranemen	74	32	2.2	1.2
Transportation, total	678	504	20.0	18.7
Locomotive engineers	180	159	5.3	5.9
Locomotive firemen	231	173	6.8	6.4
Trip riders or brakemen	179	121	5.3	4.5
Switchmen	88	25	2.6	0.9
Truck operators	-	26	-	1.0
Miscellaneous, total	300	283	8.9	10.5
Dump men	107	64	3.2	2.4
Laborers	193	185	5.7	6.8
Pump men	-	34	-	1.3
Repairs and maintenance, total	1,153	999	34.1	36.7
Machinists and helpers	130	98	3.8	3.6
Blacksmiths and helpers	103	71	3.1	2.6
Carpenters and helpers	81	52	2.4	1.9
Electricians	-	55	-	2.0
Trackmen	795	526	23.5	19.4
Repairmen	-	101	-	3.7
Watchmen	44	38	1.3	1.4
Oilers	-	39	-	1.4
Pipemen	-	19	-	0.7
All other employees[d] (not classified)	424	481	12.6	17.7
Grand total	3,377	2,710	100.0	100.0
Average number employed in active pay-roll periods as reported to Bureau of Mines for the calendar year	8,999	4,704		
Percent sample is of total	37.5	57.6		

[a]Data from Wages and Hours of Labor in Metalliferous Mines, 1924 (U. S. Dept. Labor, Bur. Labor Statistics, Bull. No. 394, Aug. 1925), and from Wages and Hours of Labor in Metalliferous Mines, 1924 and 1931 (U. S. Dept. Labor, Bur. Labor Statistics, Bull. No. 573, Jan. 1933). These bulletins contain definitions of occupations designated.

[b]Men that customarily worked in more than one occupation were tabulated under each occupation worked. This has resulted in a number of duplications which probably do not exceed 8 percent of the total tabulated.

[c]These data are without duplications except in a few cases where one employee was replaced by another during the survey period; in such a case two employees were tabulated although there was one position. Employees that performed the functions of more than one of the designated occupations were classified under the occupation to which they devoted most of their time.

[d]Includes "those occupations in which there was not a sufficient number of wage earners to warrant separate tabulation." With others these include stock-pile engineers and track-moving machine operators.

Table A-16.- NUMBER OF EMPLOYEES AT UNDERGROUND IRON MINES IN MICHIGAN, MINNESOTA, AND ALABAMA IN 1924 AND 1931, BY OCCUPATION[a]

(Data are for 38 mines in 1924 and for 28 mines in 1931)

Occupation	Number of employees for a pay period in -		Percent of total employees for a pay period in -	
	Aug.-Oct. 1924[b]	June-Oct. 1931[c]	Aug.-Oct. 1924[b]	June-Oct. 1931[c]
Primarily operating functions, total	10,018	5,108	84.04	81.83
Drilling and blasting, total	5,241	2,300	43.98	36.83
Drilling-machine operators (underground)	4,947	2,127	41.52	34.07
Drilling-machine operators' helpers (underground)	177	130	1.48	2.08
Powder men (underground)	31	28	0.26	0.45
Nippers (underground)	23	3	0.19	0.04
Roof trimmers (underground)	63	12	0.53	0.19
Loading or mucking, total	1,318	845	11.06	13.54
Loading-machine operators (underground)	83	46	0.70	0.74
Muckers and laborers (underground)	1,088	738	9.13	11.82
Chute loaders (underground)	147	61	1.23	0.98
Timbering (constructing mine supports), total	656	617	5.51	9.89
Timber framers (surface)	75	51	0.63	0.82
Timbermen (underground)	344	425	2.89	6.81
Timbermen's helpers (underground)	237	141	1.99	2.26
Transportation, total	1,425	781	11.95	12.52
Horizontal, total	1,022	503	8.57	8.06
Trammers (underground)	388	48	3.26	0.77
Motormen (underground)	241	207	2.02	3.32
Trip riders (underground)	186	90	1.56	1.44
Mule or horse drivers (underground and surface)	155	35	1.30	0.56
Dumpers (surface)	18	79	0.15	1.27
Truck operators (surface)	34	44	0.29	0.70
Vertical or inclined, total	403	278	3.38	4.46
Hoist men (underground and surface)	229	144	1.92	2.31
Cagers (underground)	19	15	0.16	0.24
Station men (underground)	17	58	0.14	0.93
Skippers (underground)	138	61	1.16	0.98
Miscellaneous, total	1,378	565	11.54	9.05
Compressor men (underground and surface)	34	26	0.28	0.42
Pump men (underground)	146	105	1.22	1.68
Engineers, stationary (surface)	39	17	0.33	0.27
Firemen, stationary (surface)	121	31	1.01	0.50
Dry-house men (surface)	78	47	0.65	0.75
Ore sorters (underground and surface)	34	-	0.29	-
Topmen (surface)	926	339	7.77	5.43
Repairs, maintenance, and some new construction, total	1,219	813	10.26	13.01
Blacksmiths (underground and surface)	110	70	0.92	1.12
Blacksmiths' helpers (underground and surface)	104	46	0.87	0.74
Carpenters (underground and surface)	170	83	1.43	1.33
Carpenters' helpers (underground and surface)	83	77	0.70	1.23
Electricians (underground and surface)	71	77	0.60	1.23
Electricians' helpers (underground and surface)	33	22	0.28	0.35
Machinists (underground and surface)	118	66	0.99	1.06
Machinists' helpers (underground and surface)	64	29	0.54	0.46
Oilers (underground and surface)	20	13	0.17	0.21
Pipemen (underground and surface)	127	84	1.07	1.35
Tool dressers (surface)	15	7	0.13	0.11
Trackmen (underground)	102	62	0.86	0.99
Trackmen's helpers (underground)	144	143	1.21	2.29
Watchmen (surface)	58	34	0.49	0.54
All other employees[d] (not classified)	679	322	5.70	5.16
Grand total	11,916	6,243	100.00	100.00
Average number employed in active pay roll periods as reported to Bureau of Mines for calendar year	25,147	14,604		
Percent sample is of total	47.4	42.7		

[a]Data from Wages and Hours of Labor in Metalliferous Mines, 1924 (U. S. Dept. Labor, Bur. Labor Statistics, Bull. No. 394, Aug. 1925), and from Wages and Hours of Labor in Metalliferous Mines, 1924 and 1931 (U. S. Dept. Labor, Bur. Labor Statistics, Bull. No. 573, Jan. 1933). These bulletins contain definitions of occupations designated.

[b]Men that customarily worked in more than one occupation were tabulated under each occupation worked. This has resulted in a number of duplications which probably do not exceed 8 percent of the total tabulated. It is believed that most of the duplications are in the groups "Drilling and blasting" and "Loading or mucking."

[c]These data are without duplications except in a few cases where one employee was replaced by another during the survey period; in such a case two employees were tabulated although there was one position. Employees that performed the functions of more than one of the designated occupations were classified under the occupation to which they devoted most of their time.

[d]Includes "those occupations in which there was not a sufficient number of wage earners to warrant separate tabulation." The following occupations were grouped by the Bureau of Labor Statistics under the designation "Other employees":

Air hammerman
Barn man
Batteryman
Blaster
Boiler cleaner
Boiler maker
Brattice man
Cable splicer
Cager's helper
Car cutter
Car hooker
Car repairman
Chainer's helper
Conveyor man
Crane operator
Demonstrator
Ditchman
Doorman
Drag foreman
Draw boss
Dumper
Fan man
First-aid station man
Fuse cutter
Hammerman
Mason
Oil-house man
Ore crusher
Painter
Pipeman's helper
Pluggerman
Rigger
Saw filer
Sawyer
Shaft pusher
Shaft repairman
Shed man
Shuttle man
Skipper's helper
Timber trammer
Tinsmith
Tool dresser's helper
Train dispatcher
Working foreman

Table A-17.- NUMBER OF PERSONS KILLED OR INJURED AND ACCIDENT RATES AT OPEN-PIT AND UNDERGROUND IRON MINES, 1914-37[a]

Year	Open-pit mines				Underground mines (excluding surface employees)				All mines (including surface shops)			
	Number of accidents		Rates per thousand 300-day workers		Number of accidents		Rates per thousand 300-day workers		Number of accidents		Rates per thousand 300-day workers	
	Killed	Injured	Killed	Injured	Killed	Injured	Killed	Injured	Killed	Injured	Killed	Injured
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1914	17	1,058	2.68	166.98	120	6,585	5.38	295.23	148	8,773	3.78	224.07
1915	18	758	3.32	140.01	78	6,631	3.64	309.18	103	8,337	2.88	233.51
1916	16	1,137	2.13	151.70	133	9,246	4.47	310.62	169	11,904	3.41	240.17
1917	36	1,709	3.71	175.98	135	8,872	4.35	285.90	191	12,278	3.54	227.54
1918	40	1,493	3.78	141.16	128	6,858	4.49	240.50	179	9,621	3.45	185.45
1919	15	813	2.50	135.64	107	6,907	3.91	252.18	139	9,098	3.09	202.35
1920	6	1,010	.68	114.93	86	6,734	3.45	269.94	106	9,072	2.34	200.49
1921	14	751	2.77	148.83	45	3,126	3.93	273.04	65	4,507	3.04	210.91
1922	15	602	2.26	90.69	64	3,700	4.20	243.09	83	4,901	3.00	177.44
1923	17	661	1.84	71.52	62	4,260	3.08	211.33	89	5,616	2.38	150.23
1924	19	510	2.60	69.70	71	3,708	3.85	201.25	97	4,959	2.95	151.01
1925	5	407	.85	69.42	68	3,850	3.65	206.84	80	5,013	2.54	159.43
1926	7	338	1.38	66.72	116	3,233	6.41	178.52	129	4,082	4.23	133.93
1927	11	314	1.99	56.73	56	2,663	3.19	151.89	73	3,409	2.45	114.64
1928	6	258	1.17	50.42	47	1,955	3.12	129.58	56	2,547	2.16	98.13
1929	19	411	3.37	72.96	58	1,732	3.90	116.58	80	2,404	2.98	89.58
1930	7	244	1.38	48.15	56	1,660	3.79	112.47	69	2,096	2.68	81.42
			Rates per million man-hours				Rates per million man-hours				Rates per million man-hours	
1931	2	104	.23	12.06	24	588	1.20	29.51	28	774	.72	19.78
1932	1	30	.37	10.99	5	204	.61	24.75	7	264	.44	16.59
1933	-	32	-	8.46	10	230	1.23	28.29	12	334	.72	19.90
1934	3	89	.55	16.32	13	345	1.06	28.18	16	485	.65	20.12
1935	4	72	.72	12.99	18	344	1.34	25.66	22	440	.89	17.63
1936	3	97	.37	12.05	24	713	1.31	38.78	29	868	.84	25.02
1937	6	128	.58	12.29	26	1,155	1.02	45.11	33	1,383	.72	30.12

[a]Data for 1914-32 from Metal Mine Accidents in the United States (U. S. Dept. Com., Bur. Mines), Bulletins No. 282 (1927), p. 81; No. 362 (1932), pp. 72-3; No. 374 (1933), p. 3; and No. 377 (1934), p. 3; data for 1933-35 from Metal Mine Accidents in the United States (U. S. Dept. Int., Bur. Mines), Bulletins No. 398 (1936), pp. 9, 42; No. 410 (1938), p. 7; and for 1936-37 from Employment and Accidents at Iron-Ore Mines in the United States, 1936 and 1937 (U. S. Dept. Int., Bur. Mines, No. H. S. S. 255, mimeo., Aug. 31, 1938), pp. 4, 6, 7. Beneficiating plants are excluded.

Table A-18.- IRON ORE PRODUCED IN THE UNITED STATES FROM OPEN-PIT AND UNDERGROUND MINES CLASSIFIED BY OUTPUT PER MAN-HOUR, 1957[a]

Average output of merchantable ore per man-hour (Gross tons)	Producing mines		Merchantable ore produced					
			Concentrated ore		Direct-shipping ore[b]		Total	
	Number	Average output per mine (Gross tons)	Gross tons	Percent of total from mines with designated productivity	Gross tons	Percent of total from mines with designated productivity	Gross tons	Percent of total by designated mining method
Open-pit mines								
(Class interval of 0.10)								
0.0 - 0.09	-	-	-	-	-	-	-	-
0.1 - 0.19	15[c]	625	-	-	9,369	100.0	9,369	(d)
0.2 - 0.29	25[c]	7,800	138,347	70.9	56,654	29.1	195,001	0.4
0.3 - 0.39	11[c]	14,046	95,887	62.1	58,622	37.9	154,509	0.3
0.4 - 0.49	9	33,866	271,708	89.1	33,088	10.9	304,796	0.6
0.5 - 0.59	2	18,967	-	-	37,934	100.0	37,934	0.1
0.6 - 0.69	2	43,288	84,624	97.7	1,951	2.3	86,575	0.2
0.7 - 0.79	1	99,491	-	-	99,491	100.0	99,491	0.2
0.8 - 0.89	2	29,968	8,028	13.4	51,907	86.6	59,935	0.1
0.9 - 0.99	4	113,580	222,912	49.1	231,408	50.9	454,320	1.0
(Class interval of 0.50)								
1.0 - 1.49	5	220,496	375,680	34.1	726,801	65.9	1,102,481	2.3
1.5 - 1.99	20.5	170,864	3,037,916	86.7	464,788	13.3	3,502,704	7.4
2.0 - 2.49	4.5	421,697	980,341	51.7	917,296	48.3	1,897,637	4.0
2.5 - 2.99	9	767,054	2,403,508	34.8	4,499,981	65.2	6,903,489	14.5
(Class interval of 2.00)								
3.0 - 4.99	10	611,834	2,068,967	33.8	4,049,369	66.2	6,118,336	12.9
5.0 - 6.99	5	718,246	-	-	3,591,230	100.0	3,591,230	7.6
7.0 - 8.99	4	4,434,264	-	-	17,737,054	100.0	17,737,054	37.4
9.0 - 10.99	2	2,598,120	-	-	5,196,240	100.0	5,196,240	11.0
United States total	131	362,222	9,687,918	20.4	37,763,183	79.6	47,451,101	100.0
Underground mines								
(Class interval of 0.10)								
0.0 - 0.09	2.5	793	732	36.9	1,250	63.1	1,982	(d)
0.1 - 0.19	2	2,087	-	-	4,174	100.0	4,174	(d)
0.2 - 0.29	7	173,481	1,164,983	95.9	49,387	4.1	1,214,370	4.9
0.3 - 0.39	6	96,214	193,753	33.6	383,530	66.4	577,283	2.4
0.4 - 0.49	1.5	65,776	-	-	98,664	100.0	98,664	0.4
0.5 - 0.59	9.5	322,860	98,449	3.2	2,968,722	96.8	3,067,171	12.5
0.6 - 0.69	13	343,101	-	-	4,460,313	100.0	4,460,313	18.1
0.7 - 0.79	7	430,865	-	-	3,016,052	100.0	3,016,052	12.2
0.8 - 0.89	8	423,228	56,301	1.7	3,329,519	98.3	3,385,820	13.7
0.9 - 0.99	10	499,502	305,539	6.1	4,689,483	93.9	4,995,022	20.3
(Class interval of 0.50)								
1.0 - 1.49	8	262,538	-	-	2,100,301	100.0	2,100,301	8.5
1.5 - 1.99	3.5	491,799	-	-	1,721,295	100.0	1,721,295	7.0
2.0 - 2.49	-	-	-	-	-	-	-	-
2.5 - 2.99	-	-	-	-	-	-	-	-
(Class interval of 2.00)								
3.0 - 4.99	-	-	-	-	-	-	-	-
5.0 - 6.99	-	-	-	-	-	-	-	-
7.0 - 8.99	-	-	-	-	-	-	-	-
9.0 - 10.99	-	-	-	-	-	-	-	-
United States total	78	315,929	1,819,757	7.4	22,822,690	92.6	24,642,447	100.0

[a]Based on reports of iron-mining companies to the U. S. Bureau of Mines. In a few instances data did not permit the segregation of production and employment for individual mines. In such cases the productivity of the group of two or more mines combined was used; the production of 22 such groups, including 53 mines, amounted to 10.6 percent of the total. Mines that used a combination of open-pit and underground methods were split up and output per man-hour was computed separately for each part. As a result of this procedure the quantities of ore produced at mines with designated productivities are a little different from the quantities shown in table A-7, in which each mine was treated as a unit in computing output per man.

[b]Represents ore that did not require concentration before shipment and includes ore that was simply crushed or screened.

[c]Exclusive of an undetermined number of small open-pit operations in Alabama, Georgia, and Missouri. The output of these pits, aggregating 49,611 gross tons, is included in the total production for the United States.

[d]Less than 0.1 percent.

Table A-19.- QUANTITY AND TENOR OF ORE PRODUCED, OVERBURDEN REMOVED, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT OPEN-PIT IRON MINES AND BENEFICIATING PLANTS ON THE MESABI RANGE, MINNESOTA, 1923-38[a]

Year	Ore produced and waste handled							Overburden removed			Total quantity of material removed (Gross tons)	Man-hours worked	Output per man-hour (Gross tons)		
	Total ore mined (Gross tons)	Crude ore sent to concentrators (Gross tons)	Merchantable ore produced (Gross tons)												
			Concentrates recovered	Direct-shipping ore	Total			Cubic yards	Cubic yards of overburden removed per ton of merchantable ore produced	Gross tons			Merchantable ore	Total ore mined	Total ore and waste excavated
					Ore	Iron (natural) contained									
						Gross tons	Per cent								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
					(3)+(4)		(6)÷(5)		(8)÷(5)	(8) x 1.25[b]	(1)+(10)		(5)÷(12)	(1)÷(12)	(11)÷(12)
1923	38,534,565	10,719,117	6,865,659	27,815,448	34,681,107	18,187,018	52.44	21,623,318	0.623	27,029,148	65,563,713	24,721,813	1.403	1.559	2.652
1924	24,607,220	6,978,369	4,627,762	17,628,851	22,256,613	11,695,017	52.55	25,606,727	1.151	32,008,409	56,615,629	19,479,442	1.143	1.263	2.906
1925	29,654,690	9,635,804	6,273,818	20,018,886	26,292,704	13,812,606	52.53	17,613,658	.670	22,017,072	51,671,762	15,025,876	1.750	1.974	3.439
1926	32,944,075	7,264,410	4,447,108	25,679,665	30,126,773	15,820,107	52.51	11,356,509	.377	14,195,636	47,139,711	12,767,529	2.360	2.580	3.692
1927	29,375,913	7,506,551	4,593,730	21,869,362	26,463,092	13,879,957	52.45	13,343,175	.504	16,678,969	46,054,882	14,024,832	1.887	2.095	3.284
1928	32,090,426	8,354,713	5,024,538	23,735,713	28,760,251	15,036,094	52.28	14,688,264	.511	18,360,330	50,450,756	13,052,675	2.203	2.459	3.865
1929	40,119,388	10,806,390	6,187,564	29,312,998	35,500,562	18,437,528	51.94	14,728,208	.415	18,410,260	58,529,648	15,912,737	2.231	2.521	3.678
1930	29,896,370	10,720,910	5,918,477	19,175,460	25,093,937	13,042,748	51.98	16,618,525	.662	20,773,156	50,669,526	14,915,362	1.682	2.004	3.397
1931	14,194,037	5,721,424	3,456,484	8,472,613	11,929,097	6,180,538	51.81	10,114,427	.848	12,643,034	26,837,071	8,277,483	1.441	1.715	3.242
1932	3,663,691	2,441,897	1,429,672	1,221,794	2,651,466	1,406,961	53.06	4,464,797	1.684	5,580,996	9,244,687	2,884,747	0.919	1.270	3.205
1933	12,206,852	4,393,334	2,449,702	7,813,518	10,263,220	5,325,523	51.89	2,649,803	.258	3,312,254	15,519,106	4,450,991	2.306	2.743	3.487
1934	13,805,814	4,301,465	2,611,729	9,504,349	12,116,078	6,249,346	51.58	4,710,894	.389	5,888,617	19,694,431	5,931,201	2.043	2.328	3.320
1935	18,974,186	7,708,523	4,269,980	11,265,663	15,535,643	8,115,287	52.24	4,794,645	.309	5,993,306	24,967,492	5,337,914	2.910	3.555	4.677
1936	31,015,056	10,137,733	6,118,402	20,877,323	26,995,725	13,945,877	51.66	6,419,178	.238	8,023,972	39,039,028	8,726,588	3.094	3.554	4.474
1937	48,209,539	14,644,509	8,712,313	33,565,030	42,277,343	21,902,448	51.81	10,819,297	.256	13,524,121	61,733,660	12,370,548	3.418	3.897	4.990
1938	12,777,909	4,388,829	2,526,193	8,389,080	10,915,273	5,720,064	52.40	7,570,236	.694	9,462,797	22,240,707	6,148,000[c]	1.775[c]	2.078[c]	3.618[c]

[a]All data, except quantity of overburden removed, from reports of iron-mining companies to the U. S. Bureau of Mines. Data on overburden removed from Annual Report of the Inspector of Mines, St. Louis County, Minnesota, and Annual Report of the Inspector of Mines, Itasca County, Minnesota, for each year designated.

[b]One cubic yard of overburden on the Mesabi range weighs approximately 1.25 gross tons. See L. C. Moore, "Open-Pit Transport on the Mesabi Range-II," Engineering and Mining Journal, Vol. 139, No. 11 (Nov. 1938), p. 52.

[c]Preliminary.

Table A-20.- DEPTH OF UNDERGROUND IRON MINES IN THE UNITED STATES IN 1937, BY STATE AND RANGE[a]

State and range	Mines reporting maximum vertical depth of shaft or shafts used for hoisting ore		Mines reporting vertical depth from which material was hoisted		Average depth of shafts[b] (Feet)	
	Number of mines	Merchantable ore produced (Gross tons)	Number of mines	Merchantable ore produced (Gross tons)	Maximum vertical depth of shaft or shafts used for hoisting ore	Vertical depth from which material was hoisted
Michigan and Wisconsin						
Gogebic range	10	4,318,427	9	4,146,396	2,456	2,135
Marquette range	11	4,701,236	9	3,972,425	1,401	1,153
Menominee range	10	1,584,683	9	1,426,487	883	744
Total	31	10,604,346	27	9,545,308	1,754	1,519
Minnesota						
Mesabi range[c]	10	3,251,224	10	3,251,224	357	338
Vermilion range	4	1,514,292	4	1,514,292	1,404	1,200
Total	14	4,765,516	14	4,765,516	690	612
Alabama[d]	6	5,098,297	6	5,098,297	1,288	1,288
New York, New Jersey, and Pennsylvania	5	747,808	4	641,450	1,051	993
United States	56	21,215,967[e]	51	20,050,571[f]	1,378	1,228

[a]Based on reports of iron-mining companies to the U. S. Bureau of Mines.

[b]In computing the average, the depth of each mine was weighted by the amount of merchantable ore produced.

[c]Includes one mine on the Cuyuna range.

[d]Excludes slope mines.

[e]Represents 86 percent of the total production from underground mines.

[f]Represents 81 percent of the total production from underground mines.

Table A-21.- MAXIMUM VERTICAL DEPTH OF 23 IDENTICAL UNDERGROUND IRON MINES IN THE LAKE SUPERIOR DISTRICT, IN 1916 AND 1937, BY STATE AND RANGE[a]

State and range	1916			1937		
	Number of mines	Ore shipments (Gross Tons)	Weighted average maximum vertical depth[b] (Feet)	Number of mines	Ore shipments (Gross tons)	Weighted average maximum vertical depth[b] (Feet)
Michigan and Wisconsin						
Gogebic range	7	2,913,695	1,978	7	3,257,259	2,595
Marquette range	5	993,913	1,167	5	2,771,791	1,393
Menominee range	5	453,589	363	5	875,301	858
Total	17	4,361,197	1,625	17	6,904,351	1,893
Minnesota						
Mesabi range[c]	3	1,648,936	398	3	1,237,686	504
Vermilion range	3	1,142,557	1,291	3	1,216,096	1,467
Total	6	2,791,493	763	6	2,453,782	981
Lake Superior District	23	7,152,690[d]	1,289	23	9,358,133[e]	1,655

[a]Data for 1916 from The Iron Ores of Lake Superior (Cleveland, Ohio: The Penton Press Co., 1917), pp. 115-311; for 1937 data on depths from reports of iron-mining companies to the U. S. Bureau of Mines and data on shipments from Lake Superior Iron Ores: 1938 (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), pp. 100-277.

[b]In computing the average, the depth of each mine was weighted by the amount of ore shipped from that mine.

[c]Includes one mine on the Cuyuna range.

[d]Represents about 20 percent of the total shipments from underground mines.

[e]Represents about 33 percent of the total shipments from underground mines.

Table A-22.- PRODUCTION, MAN-HOURS, AND OUTPUT PER MAN-HOUR AT UNDERGROUND IRON MINES IN THE UNITED STATES, BY MINING METHOD AND STATE, 1929-37[a]

Mining method and State	Merchantable ore produced: Gross tons	Percent of total United States underground production	Total man-hours worked	Tons per man-hour
Open-stope mining				
In stopes with natural supports (including room-and-pillar and sublevel stoping)				
Alabama	32,080,777	20.4	58,362,601	0.550
Minnesota[b]	2,384,744	1.5	5,998,101	.398
Michigan and Wisconsin	12,496,131	7.9	18,600,047	.672
New York, New Jersey, and Pennsylvania	4,003,893	2.6	14,265,900	.281
All other States	697,453	0.5	1,703,494	.409
United States	51,662,998	32.9	98,930,143	.522
In stopes artificially supported (shrinkage stoping)				
Michigan and Wisconsin[c]	1,244,695	0.8	1,885,255	.659
New York, New Jersey, and Pennsylvania[d]	3,387,376	2.2	8,856,297	.383
All other States	41,100	(e)	98,880	.416
United States	4,673,071	3.0	10,842,432	.431
Total open-stope mining				
Alabama	32,080,777	20.4	58,362,601	.550
Minnesota	2,384,744	1.5	5,998,101	.398
Michigan and Wisconsin	15,740,726	8.7	20,485,302	.671
New York, New Jersey, and Pennsylvania	7,391,269	4.8	23,121,197	.320
All other States	739,553	0.5	1,802,374	.410
United States	56,336,969	35.9	109,772,575	.513
Mining by caving stopes				
Top-slicing				
Minnesota	34,614,704	22.0	43,293,671	.800
Michigan and Wisconsin	19,402,074	12.3	30,807,407	.630
United States	54,016,778	34.3	74,101,078	.729
Sublevel caving				
Minnesota	4,429,822	2.8	5,123,963	.865
Michigan and Wisconsin	19,364,210	12.3	33,765,820	.573
All other States[f]	1,426,523	0.9	1,724,790	.828
United States	25,222,555	16.0	40,614,573	.621
Total mining in caving stopes				
Minnesota[g]	40,490,678	25.7	50,118,293	0.808
Michigan and Wisconsin[h]	40,659,599	25.8	68,944,614	.607
All other States	1,426,523	0.9	1,724,790	.828
United States	82,576,800	52.4	118,787,697	.695
Combination of open-stoping and caving methods				
Minnesota	112,867	0.1	299,157	.377
Michigan and Wisconsin	14,599,715	9.3	21,301,694	.685
New York, New Jersey, and Pennsylvania	61,697	(e)	113,960	.541
United States	14,774,279	9.4	21,714,811	.680
Method of mining unreported				
Alabama	28,133	(e)	62,960	.447
Minnesota	1,469,064	0.9	1,712,374	.858
Michigan and Wisconsin	1,984,045	1.3	3,887,707[i]	.603
New York, New Jersey, and Pennsylvania	38,964	(e)	136,568	.285
All other States	131,147	0.1	476,406	.276
United States	3,651,373	2.3	6,676,015	.643
Nonproducing mines[j]				
Alabama	-	-	330,000	-
Minnesota	-	-	1,509,562	-
Michigan and Wisconsin	-	-	1,678,868	-
New York, New Jersey, and Pennsylvania	-	-	69,262	-
All other States	-	-	50,156	-
United States	-	-	3,867,838	-
Grand total for underground mines				
Alabama	32,108,910	20.4	58,755,561	.546
Minnesota	44,457,373	28.2	59,637,487	.745
Michigan and Wisconsin	70,984,065	45.1	113,651,075	.626
New York, New Jersey, and Pennsylvania	7,491,930	4.8	23,440,987	.320
All other States	2,298,223	1.5	4,033,726	.570
United States	157,340,521	100.0	259,518,836	.606

[a] Data from reports of iron-mining companies to the U. S. Bureau of Mines.

[b] Includes the cut-and-fill method at one mine.

[c] Includes one small operation that reported using the cut-and-fill method in Michigan in 1929.

[d] Includes one operation that reported using the cut-and-fill method during the 9-year period.

[e] Less than 0.1 percent.

[f] Includes one operation that reported using the block-caving method throughout the 9-year period.

[g] Includes 1,446,182 gross tons of ore and 1,700,659 man-hours worked in mines that reported using a combination of top-slicing and sublevel-caving methods. These mines produced 0.9 percent of the total United States underground production for the 9-year period.

[h] Includes 1,893,315 gross tons of ore and 2,371,287 man-hours worked in mines in Michigan that reported using a combination of top-slicing and sublevel-caving methods. These mines produced 1.2 percent of the total United States underground production for the 9-year period.

[i] Exclusive of man-hours worked to produce 1,822 gross tons of ore in Wisconsin during 1929-31. These man-hours could not be segregated, and are therefore included in the other classifications.

[j] Includes idle mines and those having development, maintenance, or repair work but no production.

Table A-23.- PRODUCTION OF IRON ORE AND ESTIMATED ORE RESERVES IN THE UNITED STATES, BY KIND OF ORE, 1938

Total quantity of	Commercial or available ore reserves [b]	Ore reserves that are submarginal [b] (due to either technical or economic reasons)	Production of crude ore [c]	Estimated years of future life of available reserves, [d]

Table A-25.- PRODUCTION OF IRON ORE AND ESTIMATED ORE RESERVES IN THE UNITED STATES, BY KIND OF ORE, 1938

Area	Total quantity of merchantable ore produced [a]		Commercial or available ore reserves [b]				Ore reserves that are submarginal [b] (due to either technical or economic reasons)				Production of crude ore [c] (thousands of gross tons)		Estimated years of future life of available reserves, [d] assuming same annual production as in -	
	Thousands of gross tons	Period covered	Principal kind of ore	Thousands of gross tons	Date of estimate and authority: Date	Date of estimate and authority: Authority	Principal kind of ore	Thousands of gross tons	Date of estimate and authority: Date	Date of estimate and authority: Authority	Annual average 1922-30	1937	1922-30	1937
United States, total	2,248,893 [e]	1810-1938		5,038,000				72,947,000 [f]			70,540	80,906	71	62
Lake Superior District, total	1,724,842	1854-1938	Hematite	1,421,783 [g]			Low-grade ores and taconite	67,660,000 [h]	1926	O. E. Kuhn	55,721	67,891	26	21
Marquette range, Mich.	197,628	1854-1938	"	49,869	1/1/38	Mich. Dept. of Conservation	"	16,000,000	"	"	3,870	5,631	13	9
Menominee " Mich. & Wis.	122,849	1877-1938	"	58,032	"	"	"	7,360,000	"	"	4,735	2,293	12	25
Gogebic " " "	209,479	1884-1938	"	46,176	"	"	"	4,000,000	"	"	6,224	5,316	7	9
Vermilion range, Minn.	65,735	1884-1938	"	14,393	5/1/37	Minn. Tax Commission	"	1,000,000	"	"	1,484	1,514	10	10
Mesabi " "	1,043,720	1892-1938	"	1,191,038	"	"	"	39,000,000	"	"	38,114	52,405	31	23
Cuyuna " "	25,431	1911-1938	"	62,275	"	"	"	300,000	"	"	1,294	732	48	85
Northeastern States:														
New York, total	45,060 [i]	1880-1938	Magnetite and hematite	927,000	1/1/38		n.a.	n.a.	-	-	948	1,728	978	536
			Magnetite	898,000 [j]	"	H. U. Roche	n.a.	n.a.	-	-				
			Hematite	29,000 [k]	"	C. W. Hayes	Hematite	570,000 [l]	1909	C. W. Hayes				
New Jersey	29,353 [m]	1685-1938	Magnetite	603,000 [j]	1/1/38	H. W. Roche	n.a.	n.a.	-	-	329	970	1,833	622
Pennsylvania, total	57,534 [i]	1740-1938	Magnetite, carbonate, and brown ore	128,000	1/1/38		n.a.	n.a.	-	-	988	1,703	130	75
			Magnetite	72,000 [n]	"	O. E. Kuhn	n.a.	n.a.	-	-				
			Carbonate	46,000 [n]	"	"	n.a.	n.a.	-	-				
			Brown ore	10,000 [n]	"	"	n.a.	n.a.	-	-				
Southern States:														
Birmingham Dist., Ala., total	126,000 [o]	1880-1938	Hematite and brown ore	1,003,000	1/1/39		n.a.	n.a.			7,848	6,424	128	156
			Hematite	1,000,000 [p] [q]	"	E. F. Burchard	Hematite	1,000,000 [pr]	1/1/39	E. F. Burchard				
			Brown ore	3,000 [p]	"	"	Brown ore	n.a.	-	-				
Texas [s]	638 [t]	1855-1938	Brown ore	139,000	1/1/38	E. B. Eckel	Brown ore	37,000 [u]	1/1/38	E. B. Eckel	(v)	(v)	(v)	(v)
All other areas in the South, including Tenn., Ky., Ala. (other than Birmingham Dist.), Va., W. Va., Ga., and N.C., total	33,040	1908-1938	Hematite and brown ore	104,800 [w]	1/1/38	E. F. Burchard	Hematite, magnetite, and brown ore	2,300,000			(v)	(v)	(v)	(v)
							Hematite and brown ore	1,800,000 [w]	1927	E. F. Burchard				
							Hematite, magnetite, and brown ore	500,000 [x]	1935	Leith & Liddell				
Central States:														
Ohio	1,352	1889-1938	n.a.	n.a.	-	-	Carbonate	200,000 [y]	1926	O. E. Kuhn	(v)	(v)	(v)	(v)
Indiana	n.a.	n.a.	Carbonate	25,000 [n]	1/1/38	O. E. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)
Iowa (Waukon Dist.)	44	1900-1933	n.a.	n.a.	-	-	Brown ore	10,000 [z]	1935	Leith & Liddell	(v)	(v)	(v)	(v)
Missouri	3,435	1889-1938	Hematite	74,000 [n]	1/1/38	O. E. Kuhn	n.a.	50,000	1926	O. E. Kuhn	(v)	(v)	(v)	(v)
St. François County [aa]			Brown ore and hematite	1,000	1935	Leith & Liddell	n.a.	n.a.	-	-				

See footnotes at end of table.

Table A-23.- PRODUCTION OF IRON ORE AND ESTIMATED ORE RESERVES IN THE UNITED STATES, BY KIND OF ORE, 1938 - Continued

Area	Total quantity of merchantable ore produced [a]		Commercial or available ore reserves [b]				Ore reserves that are submarginal [b] (due to either technical or economic reasons)				Production of crude ore [c] (thousands of gross tons)		Estimated years of future life of available reserves, [d] assuming same annual production as in -	
	Thousands of gross tons	Period covered	Principal kind of ore	Thousands of gross tons	Date of estimate	Authority	Principal kind of ore	Thousands of gross tons	Date of estimate	Authority	Annual average 1922-30	1937	1922-30	1937
Western States (excluding Texas):														
Wyoming	14,325	1906-1938	Hematite	15,000[n]	1/1/38	O. R. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)
Sunrise mine			Hematite	10,000	1935	Leith & Liddell	n.a.	n.a.	-	-				
Iron mountain			n.a.	n.a.	-	-	Magnetite [bb]	Several hundred million tons	1935	Leith & Liddell				
Seminoe mountain			Hematite and magnetite	1,000	1935	Leith & Liddell	n.a.	n.a.	-	-				
Colorado	4,267	1889-1938	Magnetite	3,000[n]	1/1/38	O. R. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)
Sangre de Cristo mts.			Brown ore [cc]	5,000	1935	Leith & Liddell	n.a.	n.a.	-	-				
Taylor Peak (Cooper Creek)			n.a.	n.a.	-	-	Magnetite	3,500 [dd]	1908	E. C. Harder				
New Mexico	4,433	1906-1938	Hematite	14,000[n]	1/1/38	O. R. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)
Hanover-Fierro Dist.			Hematite and magnetite	2,000	1935	Leith & Liddell	n.a.	n.a.	-	-				
Ancho Dist.			n.a.	n.a.	-	-	n.a.	10,000	1935	Leith & Liddell				
Utah	3,698	1906-1938	Magnetite and hematite	77,000[n]	1/1/38	O. R. Kuhn	n.a.	1,000,000	1926	O. R. Kuhn	(v)	(v)	(v)	(v)
Iron Springs Dist.			All grades	40,000[ee]	1908	Leith & Harder	n.a.	n.a.	-	-				
Nevada [ff]	425	1906-1938	Magnetite and hematite	7,000[n]	1/1/38	O. R. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)
Washington (Cle Elum)	85	1907-1938	n.a.	n.a.	-	-	Hematite and magnetite	5,000	1935	Leith & Liddell	(v)	(v)	(v)	(v)
Oregon (Portland)	53	1891-1938	n.a.	n.a.	-	-	Brown ore	1,500	1935	Leith & Liddell	(v)	(v)	(v)	(v)
California	130	1907-1938	Hematite	197,000[n]	1/1/38	O. R. Kuhn	Magnetite	190,000	1935	Leith & Liddell	(v)	(v)	(v)	(v)
Montana	144	1905-1938	Hematite	300,000[n]	1/1/38	O. R. Kuhn	n.a.	n.a.	-	-	(v)	(v)	(v)	(v)

[a] Data are from reports of iron-mining companies to the U. S. Geological Survey and the U. S. Bureau of Mines. For the United States, the Lake Superior District, New Jersey, and Texas, data represent the period since ore was first mined in these areas. Production data for other States begin with years when such data were first available rather than when ore was first mined. If earlier data were available, the totals would be higher, especially in the older mining areas in eastern United States.

[b] Unless noted otherwise, data are from Kenneth Leith and Donald M. Liddell, The Mineral Reserves of the United States and Its Capacity for Production (National Resources Committee, mimeo., Mar. 1936), pp. 97-110, and O. R. Kuhn, "World's Iron-Ore Reserves Now Exceed 57,000,000,000 Tons," Engineering and Mining Journal, Vol. 122, No. 3 (July 17, 1926), pp. 84-5, 90.

[c] Data are from reports of iron-mining companies to the U. S. Bureau of Mines.

[d] These estimates are probably too low for the Lake Superior District. They are based on conservative estimates of high-grade ore proven to exist by drill holes. In 1926, Kuhn (op. cit., p. 90) estimated the available ore reserves in the Lake Superior District at 2,647,225,000 gross tons. Deducting the half billion tons of crude ore mined during 1926-37, the total is still about 700 million higher than that shown in this table. It is expected that further discoveries will add considerably to the present-known tonnages. It is estimated that future discoveries are likely to add 15 percent to the present reserves on the Mesabi range and to increase the life expectancy of the Michigan and Wisconsin ranges as much as 40 percent. See Leith and Liddell, op. cit., p. 98. Moreover, ore not classed as available now may, as a result of beneficiation progress, become available in the future.

[e] Represents production so far as it has been recorded or estimated. Data for the years prior to 1860 were estimated from pig-iron production and include both imported and domestic ore.

[f] Total for areas for which tonnage had been estimated.

[g] From Lake Superior Iron Ores: 1938 (Cleveland, Ohio: The Lake Superior Iron Ore Assoc., 1938), p. 111. Data for Minnesota do not include the tonnage of ore on State lands that are not under lease, and do not include the tonnage of low-grade nonmerchantable ore which is carried on the tax records. Data for Michigan are exclusive of low-grade siliceous ores.

[h] In 1935 Leith and Liddell estimated the reserves of low-grade ores and taconites, not economically beneficiable, at 72 billion tons, and in 1937 H. M. Roche stated that if this reserve of low-grade ore averaged 35 percent iron and could be concentrated to 60 percent iron at a loss of 5 percent iron in the tailing, it would contain 40 billion tons of 60 percent iron concentrate. See H. M. Roche, "The Iron Ores of New Jersey," The Iron Age, Vol. 139, No. 5 (Feb. 4, 1937), p. 70.

[i] Data for 1880 and 1889 were obtained from U. S. Census reports, and data for 1881-88 were estimated by the authors from fragmentary data for some of the mines. Data for Pennsylvania prior to 1880 represent production from the Cornwall mines only.

[j] Brought up to date by subtracting from the tonnage, estimated by Roche, at the beginning of 1937 the crude ore mined in 1937. For original estimate see Roche, op. cit., pp. 74-7, and H. M. Roche, "The Iron Ores of New Jersey," The Iron Age, Vol. 139, No. 7 (Feb. 18, 1937), p. 48.

[k] Brought up to date by subtracting from Hayes' estimate, made in 1909, the crude ore mined during 1909-37. For

[l] Not computed, as the result would be of little value. Production of ore was irregular and the estimates of available ore reserves vary widely.

[m] Data are for the Tennessee River Basin, including Western Kentucky, Northeastern and Northwestern Alabama, Northwestern Georgia, Southwestern Virginia, and Northeastern, Southeastern, and West-Middle Tennessee. Northcutt's original estimate of available reserves, made in 1927, was brought up to date by subtracting the

[j] Brought up to date by subtracting from the tonnage, estimated by Roche, at the beginning of 1937 the crude ore mined in 1937. For original estimate see Roche, op. cit., pp. 74-7, and H. M. Roche, "The Iron Ores of New Jersey," The Iron Age, Vol. 139, No. 7 (Feb. 18, 1937), p. 42.

[k] Brought up to date by subtracting from Hayes' estimate, made in 1909, the crude ore mined during 1909-37. For original estimate see C. W. Hayes, "Iron Ores of the United States," Papers on the Conservation of Mineral Resources (U. S. Dept. Int., Geol. Survey, Bull. No. 394, 1909), p. 90.

[l] Ibid.

[m] Data for 1609-1911 from H. M. Roche, "The New Magnetic Concentrating Mill at the Richard Iron Mine, New Jersey - I," Engineering and Mining Journal-Press, Vol. 115, No. 21 (May 26, 1923), p. 923; data for subsequent years from reports of iron-mining companies to the U. S. Bureau of Mines.

[n] Brought up to date by subtracting from Kuhn's estimate, made in 1926, the crude ore mined during 1926-37.

[o] Represents 169,659,372 gross tons of red ore and 16,160,642 gross tons of brown ore. Data for 1880-1936 from E. F. Burchard, "Iron Ore Available to Alabama Blast Furnaces," Mining and Metallurgy, Vol. 19, No. 376 (Apr. 1938), pp. 183-4. To these data were added the quantity of merchantable ore produced in 1937 and 1938, this being obtained from reports of iron-mining companies to the U. S. Bureau of Mines.

[p] Available and submarginal ore reserves were estimated specially for this study by E. F. Burchard, U. S. Geological Survey.

[q] Represents ore above 3,500 to 4,000 feet. The recoverable ore is probably less than this in view of the necessity to leave some ore in pillars.

[r] Includes siliceous ore and beds more than 4,000 feet deep.

[s] Data are from Edwin H. Eckel, The Brown Iron Ores of Eastern Texas (U. S. Dept. Int., Geol. Survey, Bull. No. 902, 1939), pp. 14-5, 67.

[t] Iron ore produced prior to 1889 largely estimated on the basis of pig-iron production.

[u] This estimate for Eastern Texas excludes the enormous tonnage of low-grade ferruginous material that might possibly be used in the distant future.

[v] Not computed, as the result would be of little value. Production of ore was irregular and the estimates of available ore reserves vary widely.

[w] Data are for the Tennessee River Basin, including Western Kentucky, Northeastern and Northwestern Alabama, Northwestern Georgia, Southwestern Virginia, and Northeastern, Southeastern, and West-Middle Tennessee. Burchard's original estimate of available reserves, made in 1927, was brought up to date by subtracting the crude ore mined during 1927-37. For original estimate see U. S. Congress, House of Representatives, Tennessee River and Tributaries, North Carolina, Tennessee, Alabama, and Kentucky, H. Doc. No. 115, 70th Cong., 1st sess., 1928, pp. 118-9.

[x] Data are for areas outside of Alabama and Tennessee Valley.

[y] This tonnage was classed as available by Kuhn, but the authors have considered it more appropriately in the submarginal class. Note also that in 1935 Leith and Liddell, op. cit., p. 104, stated that, "The siderite deposits of Ohio, West Virginia, and northeast Kentucky, while extensive, are no longer considered of any importance."

[z] This tonnage is nearly available.

[aa] In 1935 deposits outside of this area were not important. See Leith and Liddell, op. cit., p. 105.

[bb] Contains a large amount of titanium.

[cc] Manganiferous brown ore.

[dd] Data are from E. C. Harder, "The Taylor Peak and Whitepine Iron-Ore Deposits, Colorado," Contributions to Economic Geology, 1908 (U. S. Dept. Int., Geol. Survey, Bull. No. 390, 1909), pt. I, p. 194. Harder's estimate was between 3 and 4 million tons. These deposits will probably never be regarded as commercial. See Leith and Liddell, op. cit., p. 107.

[ee] Data are from C. K. Leith and E. C. Harder, The Iron Ores of the Iron Springs District, Southern Utah (U. S. Dept. Int., Geol. Survey, Bull. No. 338, 1908), p. 73.

[ff] None of the deposits of Arizona and Nevada were available in 1935. See Leith and Liddell, op. cit., p. 108.

n.a. Data not available.

Table A-24.- IRON IN FERROUS MATERIALS CONSUMED IN STEELMAKING IN THE UNITED STATES, BY SOURCES, 1909-38[a]

(Thousands of gross tons)

Year	Pig iron (excluding ferro-alloys)	Iron and steel scrap			Iron ore	Total
		Home[b]	Purchased[c]	Total		
Ferrous materials consumed						
1909	18,712	5,126	4,804	9,930	835	29,477
1914	17,128	5,585	5,071	10,656	999	28,783
1919	23,920	9,343	7,026	16,369	1,052	41,341
1929	34,687	13,988	15,369	29,357	643[d]	64,687
1935	17,521	10,267	9,988	20,255	410[d]	38,186
1936	25,619	14,617	13,166	27,783	581[d]	53,983
1937	28,851	15,007	13,365	28,372	617[d]	57,840
1938	15,692	8,522	7,138	15,660	347[d]	31,699
1935-38 avg.	21,921	12,103	10,915	23,018	489	45,428
Iron in materials consumed[e]						
1909	17,215	5,044	4,727	9,771	418	27,404
1914	15,758	5,496	4,990	10,486	500	26,744
1919	22,006	9,194	6,914	16,108	530	38,644
1929	31,912	13,764	15,122	28,886	322	61,120
1935	16,119	10,103	9,828	19,931	206	36,256
1936	23,569	14,383	12,955	27,338	294	51,201
1937	26,543	14,767	13,151	27,918	312	54,773
1938	14,437	8,386	7,024	15,410	172	30,019
1935-38 avg.	20,167	11,910	10,740	22,650	246	43,063
Percent of total iron supplied by materials consumed						
1909	62.8	18.4	17.3	35.7	1.5	100.0
1914	58.9	20.6	18.6	39.2	1.9	100.0
1919	56.9	23.8	17.9	41.7	1.4	100.0
1929	52.2	22.5	24.8	47.3	0.5	100.0
1935	44.4	27.9	27.1	55.0	0.6	100.0
1936	46.0	28.1	25.3	53.4	0.6	100.0
1937	48.4	27.0	24.0	51.0	0.6	100.0
1938	48.1	27.9	23.4	51.3	0.6	100.0
1935-38 avg.	46.8	27.7	24.9	52.6	0.6	100.0

[a]Data for 1909 and 1914 from Census of Manufactures: 1914 (U. S. Dept. Com., Bur. Census, 1919), II, 226; for 1919 from Fourteenth Census of the United States: 1920, Vol. X, "Manufactures: 1919 (1923), p. 334; for 1929 from Fifteenth Census of the United States: 1930, "Manufactures: 1929" (1933), II, 962; for 1935-36 from Robert H. Ridgeway, H. W. Davis, and M. E. Trought, Consumption of Ferrous Scrap and Pig Iron in the United States in 1936 (U. S. Dept. Int., Bur. Mines, Report of Investigations 3366, mimeo., Nov. 1937), p. 9; for 1937-38 from James S. Earle, "Consumption of Ferrous Scrap and Pig Iron Lower in 1938," Mineral Market Reports (U. S. Dept. Int., Bur. Mines, No. M. M. S. 750, mimeo., June 12, 1939), p. 2.

[b]The term "home" or "plant" scrap refers to material originating within the same plant and includes such items as spills, butts, croppings, clippings, borings, turnings, mill or hammer scale, cinder, defective products discarded, etc.

[c]"Purchased" scrap refers to materials originating from sources outside of the plant. It includes purchased material, as well as scrap transferred from other plants under the same control. For the most part it represents materials salvaged from articles discarded after use, such as old rails, automobiles, stoves, and the usual assortment of junk, but a small part of it is new scrap transferred from other plants. The quantities of the latter that were consumed were 773,843 gross tons in 1909, 899,113 gross tons in 1914, 1,480,260 gross tons in 1919, and 958,170 gross tons in 1929.

[d]Data for 1929 and for 1935-38 are estimates based on the assumption that 30 pounds of iron ore were consumed for each ton of steel produced in basic open-hearth furnaces, and 20 pounds of iron ore were consumed for each ton of steel produced in acid open-hearth furnaces.

[e]The iron content of materials consumed was estimated by making the following assumptions: That the iron content of pig iron represented 92.0 percent of its weight; that 98.4 percent of the weight of scrap was iron content; and that the iron content of the iron ore consumed was approximately the same as the iron content of all iron ore produced. The percentage of iron contained in iron ore mined was reported to the U. S. Bureau of Mines for 1919, 1929, 1935, 1936, 1937, and 1938, and estimated at 50.0 percent for 1909 and 1914.

Table A-25.- DISTRIBUTION OF ROLLED-STEEL PRODUCTS OF THE UNITED STATES, BY MAJOR CONSUMING CHANNELS, 1923-38[a]

(Thousands of gross tons)

Year	Railroad industry[b]		Automobile industry		Building and construction industry[c]		Nonagricultural extractive industries[d]		Metal container industry	
	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total
1923	8,700	27.0	3,550	11.0	5,000	15.5	3,400	10.5	1,150	3.5
1924	7,700	28.0	2,700	10.0	4,900	18.0	2,450	9.0	1,100	4.0
1925	8,200	25.0	4,200	13.0	5,700	17.5	2,600	8.0	1,500	4.5
1926	8,200	23.5	5,000	14.5	6,800	19.5	3,300	9.5	1,400	4.0
1927	6,100	19.0	4,500	14.0	7,100	22.0	2,750	8.5	1,450	4.5
1928	6,000	16.0	6,700	18.0	6,100	16.5	3,500	9.5	1,850	5.0
1929	6,900	17.0	7,300	18.0	6,700	16.5	4,300	10.5	2,000	5.0
1930	4,400	15.0	4,500	15.5	5,500	19.0	3,350	11.5	1,750	6.0
1931	2,550	13.5	3,050	16.0	3,500	18.5	2,100	11.0	1,700	9.0
1932	1,250	12.0	1,750	17.0	2,050	20.0	900	8.5	1,200	11.5
1933	1,500	9.0	3,150	19.0	2,650	16.0	1,000	6.0	2,250	13.5
1934	2,000	10.6	4,000	21.3	3,250	17.3	1,350	7.2	1,850	9.8
1935	1,805	6.5	6,075	24.3	3,515	14.3	1,400	5.7	2,840	11.6
1936	3,300	10.3	6,500	20.3	4,900	15.3	1,500	4.7	3,000	9.4
1937	3,892	12.0	5,652	17.4	2,926	9.0	1,713	5.3	3,180	9.8
1938	1,172	6.6	2,740	15.5	2,689	15.2	738	4.2	1,568	8.9
1923-38	73,469	16.8	71,367	16.3	73,280	16.7	36,351	8.3	29,788	6.8

Year	Exports		Machinery and tool industry[e]		Agricultural industry[f]		All other[g]		Total distributed		Total rolled steel produced[h] (quantity)
	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total produced	
1923	1,950	6.0	950	3.0	1,300	4.0	6,300	19.5	32,300	97.1	33,277
1924	1,650	6.0	960	3.5	820	3.0	5,100	18.5	27,380	97.5	28,086
1925	1,650	5.0	1,150	3.5	1,150	3.5	6,500	20.0	32,650	97.9	33,387
1926	1,750	5.0	1,400	4.0	1,400	4.0	5,600	16.0	34,850	98.2	35,496
1927	1,800	5.5	1,300	4.0	1,800	5.5	5,500	17.0	32,300	98.2	32,879
1928	2,400	6.5	1,300	3.5	2,400	6.5	6,900	18.5	37,150	98.6	37,663
1929	2,250	5.5	1,200	3.0	2,250	5.5	7,700	19.0	40,600	98.9	41,069
1930	1,600	5.5	900	3.0	1,150	4.0	6,000	20.5	29,150	98.9	29,513
1931	750	4.0	600	3.0	850	4.5	3,900	20.5	19,000	99.1	19,176
1932	300	3.0	300	3.0	350	3.5	2,200	21.5	10,300	98.6	10,451
1933	550	3.5	500	3.0	650	4.0	4,350	26.0	16,600	99.2	16,733
1934	835	4.4	900	4.8	1,382	7.4	3,240	17.2	18,807	99.1	18,970
1935	825	3.4	1,040	4.2	2,270	9.3	4,935	20.2	24,505	102.3	23,964
1936	1,200	3.8	1,700	5.3	1,300	4.1	8,600	26.8	32,000	94.7	33,801
1937	2,357	7.2	1,224	3.8	1,120	3.4	10,468	32.1	32,532	88.5	36,766
1938	1,298	7.3	578	3.3	510	2.9	6,361	36.1	17,654	84.1	20,986
1923-38	23,165	5.3	16,002	3.7	20,702	4.7	93,654	21.4	437,778	96.8	452,219

[a]Data for 1923-34 from "Steel Consumed in 1932," The Iron Age, Vol. 131, No. 1 (Jan. 5, 1933), facing p. 8; for 1925-33 from T. H. Gerken, "Where Steel Went," The Iron Age, Vol. 135, No. 1 (Jan. 3, 1935), p. 203; for 1934-38 from "How Finished Steel Was Distributed by Consuming Channels in 1938," The Iron Age, Vol. 143, No. 11 (Mar. 16, 1939), facing p. 86.

[b]Includes railroad car and locomotive builders and parts manufacturers.

[c]Includes contractors, concrete reinforcing bar fabricators, building material and equipment manufacturers, and highway builders.

[d]Includes oil, gas, water, mining and lumbering industries, and public utilities.

[e]Includes electrical and other machinery, tool and equipment manufacturers.

[f]Includes agricultural implement and equipment manufacturers.

[g]Includes jobbers, dealers, and distributors (not including concrete bar fabricators); also includes manufactures of stamped and pressed steel products, household equipment (furniture, heating equipment, refrigerators, etc.), forgings, ships, bolts, screws, rivets, and miscellaneous other products.

[h]Data from Annual Statistical Report of the American Iron and Steel Institute for 1938 (New York: American Iron and Steel Institute, 1939), p. 22.

Table A-26.- INDICATORS OF GROWTH AMONG MAJOR IRON-CONSUMING CHANNELS IN THE UNITED STATES, 1900-38

Year	General indicators				Railroad industry[f]				Automobile industry[h]			Construction industry[j]			
	Population[a]	Tonnage of semi-finished iron and steel[b] (gross tons)	Value of exports of iron and steel mill products, machinery, and automobiles[c] [d] (thousands of dollars)	Iron ore consumed[e] (gross tons)	Ton-miles of revenue freight[g] (millions)	Railway mileage operated[g]	Passenger train car-miles (thousands)	Iron and steel rails produced (gross tons)	Number of passenger cars and motor trucks produced[i]	Number of motor vehicles (excluding motorcycles) registered	Value of automobile exports, including parts[d] (thousands of dollars)	Production of iron and steel structural shapes (gross tons)	Index of value of construction contracts awarded (1923-25 avg. = 100)	Index of construction costs[k] (monthly avg. 1923-25 = 100)	Number of nonfarm family dwelling units started (thousands)
1900	76,129,408	14,596,106	116,554	26,722,583	141,597	192,556	n.a.	2,385,682	5,000	8,000	n.a.	815,161	n.a.	n.a.	240
1901	77,747,402	17,916,511	113,944	29,357,171	147,977	195,562	n.a.	2,874,639	7,000	14,800	n.a.	1,013,150	n.a.	n.a.	340
1902	79,365,396	20,065,198	94,145	35,886,921	157,289	200,155	n.a.	2,947,933	9,000	23,000	949	1,300,326	n.a.	n.a.	360
1903	80,983,390	20,269,419	98,827	34,232,399	173,221	205,314	n.a.	2,992,477	11,235	32,920	1,207	1,095,813	n.a.	n.a.	400
1904	82,601,384	18,485,035	116,569	30,224,910	174,522	212,243	n.a.	2,284,711	22,830[l]	55,000	1,896	949,146	n.a.	n.a.	440
1905	84,219,378	26,152,151	136,631	43,433,138	186,463	216,974	n.a.	3,375,929	25,000	78,000	2,481	1,660,519	n.a.	n.a.	480
1906	85,837,372	29,468,799	263,099	49,355,343	215,878	222,340	n.a.	3,977,887	34,000	107,000	3,497	2,118,772	n.a.	n.a.	480
1907	87,455,366	30,112,672	186,208	51,879,998	236,601	227,455	n.a.	3,633,654	44,000	142,000	5,502	1,940,352	n.a.	n.a.	440
1908	89,073,360	18,514,442	183,679	32,473,268	218,382	230,494	2,705,660	1,921,015	65,000	198,000	5,278	1,083,181	n.a.	n.a.	440
1909	90,691,354	30,584,709	151,605	52,080,428	218,803	235,402	2,746,511	3,023,845	131,000	312,000	5,992	2,275,562	n.a.	n.a.	580
1910	92,267,080	32,713,999	188,311	55,246,129	235,017	240,831	2,998,171	3,636,031	187,000	469,000	11,190	2,266,890	n.a.	n.a.	500
1911	93,682,189	29,121,344	245,504	42,245,089	253,784	246,238	3,136,774	2,822,790	210,000	640,000	15,509	1,912,367	n.a.	n.a.	480
1912	95,097,298	37,353,761	289,465	58,031,118	264,081	249,852	3,235,634	3,327,915	378,000	944,000	26,435	2,846,487	n.a.	n.a.	520
1913	96,512,407	37,792,237	351,942	61,297,956	301,730	253,470	3,320,438[m]	3,502,780	485,000	1,258,000	32,982	3,004,972	n.a.	47.1	460
1914	97,927,516	28,981,509	293,420	40,613,448	288,637	256,547	3,399,604	1,945,095	569,000	1,711,000	34,591	2,031,124	n.a.	41.8	440
1915	99,342,625	38,059,305	274,747 255,476[n]	55,468,380	277,135	257,569	3,229,496	2,204,203	970,000	2,446,000	69,510 59,647[n]	2,437,003	n.a.	43.7	440
1916	100,757,735	49,429,891	777,110	72,477,485	366,173	259,705	3,409,639	2,854,518	1,618,000	3,513,000	123,064	3,029,964	n.a.	69.5	420
1917	102,172,845	51,972,157	1,125,058	70,305,415	398,263	259,705	3,485,788	2,944,161	1,874,000	4,983,000	124,476	3,110,000	n.a.	85.4	300
1918	103,587,955	50,892,186	1,003,099	71,068,260	408,778	258,507	3,376,489	2,540,892	1,171,000	6,147,000	100,889	2,849,969	n.a.	89.2	200
1919	105,003,065	40,743,975	968,265	55,826,768	367,161	258,525	3,446,787	2,203,843	1,934,000	7,565,000	156,426	2,614,036	63	93.5	460
1920	106,543,031	49,577,018	1,388,534	66,071,903	413,699	259,941	3,618,617	2,604,116	2,227,000	9,232,000	303,262	3,306,748	63	118.5	300
1921	108,207,853	22,834,923	728,340	29,425,919	309,533	258,362	3,503,514	2,178,818	1,682,000	10,463,000	83,749	1,272,624	56	95.1	432
1922	109,872,675	40,773,416	473,285	47,784,231	342,188	257,425	3,445,869	2,171,776	2,646,000	12,238,000	103,202	2,718,768	79	82.3	676
1923	111,537,497	53,192,012	618,798	71,831,863	416,256	258,084	3,616,342	2,984,516	4,180,000	15,092,000	170,612	3,405,197	84	100.9	814
1924	113,202,319	44,635,395	670,540	54,312,245	391,945	258,238	3,676,746	2,433,332	3,738,000	17,594,000	209,872	3,283,708	94	101.6	827
1925	114,867,141	52,422,994	828,979	64,872,559	417,418	258,631	3,773,114	2,785,257	4,428,000	19,937,000	318,386	3,604,130	122	97.5	894
1926	116,531,963	55,781,449	892,652	68,905,465	447,444	258,815	3,862,610	3,217,649	4,506,000	22,001,000	320,179	3,911,663	129	98.1	841
1927	118,196,785	52,330,438	981,901	70,764,555	432,014	259,639	3,850,116	2,806,486	3,580,000	23,133,000	388,528	3,742,445	129	97.3	757
1928	119,861,607	57,807,571	1,172,652	67,007,786	436,097	260,546	3,815,337	2,647,493	4,601,000	24,493,000	501,594	4,096,143	135	97.5	713
1929	121,526,429	63,401,794	1,345,912	75,861,188	450,189	260,570	3,870,903	2,722,138	5,622,000	26,501,000	541,396	4,778,020	117	97.6	510
1930	123,091,000	46,012,257	931,250	55,741,570	385,815	260,440	3,691,480	1,873,233	3,510,000	26,545,000	279,127	3,512,473	92	95.7	303

See footnotes at end of table.

Table A-26.- INDICATORS OF GROWTH AMONG MAJOR IRON-CONSUMING CHANNELS IN THE UNITED STATES, 1900-38 - Concluded

General indicators	Railroad industry[f]	Automobile industry[h]	Construction industry[j]

Table A-26.- INDICATORS OF GROWTH AMONG MAJOR IRON-CONSUMING CHANNELS IN THE UNITED STATES, 1900-38 - Concluded

Year	General indicators				Railroad industry[f]				Automobile industry[h]			Construction industry[j]			
	Population[a]	Tonnage of semi-finished iron and steel[b] (gross tons)	Value of exports of iron and steel mill products, machinery, and automobiles[c d] (thousands of dollars)	Iron ore consumed[e] (gross tons)	Ton-miles of revenue freight[g] (millions)	Railway mileage operated[g]	Passenger train car-miles (thousands)	Iron and steel rails produced (gross tons)	Number of passenger cars and motor trucks produced[i]	Number of motor vehicles (excluding motor-cycles) registered	Value of automobile exports, including parts[d] (thousands of dollars)	Production of iron and steel structural shapes (gross tons)	Index of value of construction contracts awarded (1923-25 avg.=100)	Index of construction costs[k] (monthly avg. 1923-25=100)	Number of nonfarm family dwelling units started (thousands)
1931	124,113,000	29,093,185	527,311	30,817,952	311,073	259,999	3,274,812	1,157,751	2,472,000	25,814,000	148,125	2,062,858	63	85.5	219
1932	124,974,000	14,935,931	236,377	13,339,942	235,309	258,869	2,743,437	402,566	1,431,000	24,115,000	76,255	937,228	28	74.0	94
1933	125,770,000	24,806,609	268,485	22,006,670	250,651	256,741	2,496,969	416,296	1,986,000	23,874,000	90,630	1,109,457	25	80.3	64
1934	126,626,000	28,561,485[o]	496,875	26,802,304	270,292	254,882	2,574,329	1,010,224	2,970,000	24,952,000	190,216	1,425,040	32	93.4	62
1935	127,521,000	37,362,483[o]	580,621	35,907,654	283,637	252,930	2,640,297	711,537	4,120,000	26,231,000	227,290	1,749,740	37	92.6	149
1936	128,429,000	52,304,894[o]	686,939	52,416,327	341,182	251,542	2,930,332	1,219,846	4,616,000	28,166,000	240,213	2,897,631	55	97.3	300
1937	129,257,000	56,310,088[o]	1,126,034	63,292,972	360,620[p]	250,582	3,080,215[p]	1,445,739	5,016,000	29,705,000	346,887	3,276,846	59	110.7	327
1938	130,215,000	31,351,180[o]	n.a.	32,720,281	n.a.	n.a.	n.a.	622,895	n.a.	n.a.	n.a.	1,859,540	n.a.	n.a.	360[q]

[a]Annual midyear estimates for Continental United States. Data are from Statistical Abstract of the United States, 1938 (U. S. Dept. Com., Bur. Census, 1939), p. 10.

[b]Includes steel ingots and castings and non-steelmaking pig iron. The latter includes all pig iron produced except the basic, bessemer and low phosphorous grades. Data are from Annual Statistical Report of the American Iron and Steel Institute for 1926 (New York: American Iron and Steel Institute, 1927), p. 7; same, 1937 (1938), p. 6; and same, 1938 (1939), pp. 6, 15.

[c]Data are from Statistical Abstract, 1938, p. 445.

[d]Data are for fiscal years ended June 30, through 1915 and for calendar years thereafter.

[e]Includes small quantities of manganiferous iron ore consumed; the years 1915-38 include estimates, by the authors, of small quantities of iron ore consumed by basic and acid open-hearth steelmaking furnaces. Data are from reports of mining companies to the U. S. Bureau of Mines.

[f]Except for "tons of iron and steel rails produced" data are for fiscal years ended June 30, through 1915 and for calendar years thereafter. Data are from Statistical Abstract of the United States, 1925 (U. S. Dept. Com., Bur. For. & Dom. Com., 1926), pp. 381, 383; Statistical Abstract, 1938, pp. 379, 387, 389; Annual Statistical Report of the American Iron and Steel Institute for 1933 (1934), pp. 36-7; and same, 1938, p. 22.

[g]Switching and terminal roads excluded beginning with 1908; ton-miles on a short-ton basis.

[h]Data are from Statistical Abstract, 1925, p. 364 and Statistical Abstract, 1938, pp. 370, 445.

[i]Except where noted otherwise, data are for the United States and Canada. For 1921 and subsequent years data not only include motor vehicles of United States design made by Canadian plants but also motor vehicles assembled in foreign countries from parts made in the United States.

[j]Data are from Annual Statistical Report of the American Iron and Steel Institute for 1933, pp. 36-7; same, 1938, p. 21; Statistical Abstract of the United States, 1934 (U. S. Dept. Com., Bur. For. & Dom. Com., 1934), p. 769; Statistical Abstract, 1938, pp. 834, 845; and Lowell J. Chawner, Residential Building (National Resources Committee, Housing Monograph Ser. No. 1, 1939), p. 13.

[k]Index based on the costs of lumber, steel, cement, and the rates paid common labor.

[l]For United States only.

[m]Class I and Class II roads only.

[n]Six months, July to December.

[o]Includes an estimate of the production of steel castings that were not reported to the American Iron and Steel Institute, for 1934, 1935, and 1936, as estimated by Edwin F. Cone, "Trends in Production of American Alloy Steels and of Electric Steels," Metals and Alloys, Vol. 8, No. 7 (July 1937), p. 191; for 1937 and 1938 similarly estimated by the authors.

[p]Class I roads only.

[q]Preliminary.

n.a. Data not available.

Table A-27.- PROPORTION OF POPULATION ON RELIEF IN SPECIFIED IRON-MINING COUNTIES IN THE LAKE SUPERIOR DISTRICT DURING THE YEAR ENDED JULY 1, 1934

County and State	Average number of persons on relief as percent[a] of -		Percent of United States output of iron ore in 1934[b]
	1930 population	1933 or 1934 population	
Itasca, Minn.	8.8	n.a.	13.5
Gogebic, Mich.	34.5	36.4	7.5
Iron, Mich.	28.3	30.4	2.8
Marquette, Mich.	34.1	35.2	9.5
Iron, Wis.	30.8	32.9	2.4

[a]Carter Goodrich, Bushrod W. Allin, and Marion Hayes, Migration and Planes of Living, 1920-1934 (Philadelphia, Pa.: University of Pennsylvania Press, 1935), pp. 93, 95. "Persons on relief" includes the dependents of relief recipients.

[b]Data from reports of iron-mining companies to the U. S. Bureau of Mines.

n.a. Data not available.

Table A-28.- NUMBER OF PERSONS IN SPECIFIED IRON-MINING COUNTIES IN THE UNITED STATES WHO REGISTERED IN THE UNEMPLOYMENT CENSUS OF NOVEMBER 16-20, 1937

County and State	Number registered[a]					Average number of men employed at iron mines in 1937[f]
	Totally unemployed[b]	Emergency workers[c]	Unemployed and emergency workers		Partly unemployed[e]	
			Total	Percent of 1930 population[d]		
Itasca, Minn.	1,833	616	2,449	9.0	1,181	3,112
Gogebic, Mich.	1,759	1,560	3,319	10.5	498	2,313
Iron, Mich.	1,472	1,408	2,880	13.8	311	1,252
Marquette, Mich.	2,012	742	2,754	6.2	877	2,926
Iron, Wis.	693	515	1,208	12.2	169	621
Total of five counties	7,769	4,841	12,610	9.4	3,036	10,224
United States total	5,833,401	2,011,615	7,845,016	6.4	3,219,502	25,945

[a]United States total from Census of Partial Employment, Unemployment, and Occupations: 1937 (Washington, D. C., 1938), I, 1; data for Michigan and Minnesota from same, II, 309-11, 358; for Wisconsin from same, III, 671.

Data for counties include an undetermined number of persons not attached to the iron-mining industry. On the other hand, not all unemployed persons or emergency workers registered. The enumerative house-to-house test census, during the week of November 29, in areas selected at random throughout the United States, and which covered about 1.5 percent of the population, indicated that the number of males who registered in the voluntary census in these areas was 80 percent of those canvassed in the test census and questioned about their employment status at the time of the voluntary registration. See Census of Partial Employment, Unemployment, and Occupations: 1937, vol. I, p. XV.

[b]This classification includes all persons between the ages of 15 and 74 years who registered as "totally unemployed and wanting work."

[c]This class is made up mainly of persons "working at WPA, NYA, CCC, or other emergency work." Presumably these would be unemployed but for the emergency work.

[d]Population data from Fifteenth Census of the United States: 1930, "Population" (U. S. Dept. Com., Bur. Census, 1931), I. 5, 515, 545, 1182. Population data for 1937 by counties are not available; if 1937 population data had been used, the results might have been different because of population changes.

[e]This class includes all persons who registered as "partly employed and wanting more work."

[f]From reports of iron-mining companies to the U. S. Bureau of Mines.

APPENDIX B

TECHNOLOGICAL ADVANCES IN THE TRANSPORTATION OF IRON ORE FROM LAKE SUPERIOR MINES TO SMELTERS

Although technological advances in moving iron ore after it leaves the mines are not a primary concern of this report, technical progress in the transportation and handling of Lake Superior ores warrants a brief supplementary review here for two main reasons. First, it has made more available to blast furnaces the rich iron-ore deposits in the Lake Superior District and has been an important factor in the rapidity of the growth of iron mining in this district. The many millions of dollars invested in the establishment and improvement of railroad, dock, and boat facilities have served to safeguard and encourage investments both at iron mines and at blast furnaces and steel works; they have helped to increase and perpetuate iron mining in an area which requires comparatively little labor per ton of ore and whose growth, especially prior to the World War, was an important influence in reducing unit labor requirements in iron-ore production in the United States. Secondly, improvements in the transportation and handling of iron ore between mine and smelter have resulted in important labor savings and indicate that, if the concept of iron-ore production be extended to include these activities, there would be additional increases in output per man to take into account.

In the past 50 to 75 years iron-ore transportation and loading and unloading facilities have been developed and greatly improved at all points along the route of iron ore from the Lake Superior mines to blast furnaces - in rail haulage from mines to ore-shipping docks, in loading ore boats at upper Lakes ports, in transporting ore on the Great Lakes and connecting waterways, in unloading ore at lower Lakes ports, and in ore haulage from receiving docks to blast furnaces.

IMPROVEMENTS IN RAIL HAULAGE TO ORE DOCKS[1]

The capacity and efficiency of rail transportation of iron ores from mines to docks have been greatly increased by the gradual extension

[1] For a discussion of progress made in rail transportation of iron ore by one of the oldest iron-mining enterprises in the Lake Superior District, see H. R. Harris, "Transporting Ore From Mine to Docks," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929), pp. 761-5, 770. See also John Hearding, "Early Methods of Transporting Iron Ore in the Lake Superior Region," *Proceedings of the Lake Superior Mining Institute*, Vol. XXIX (1936), pp. 174-9; and *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps, Transportation Ser. No. 1, rev. 1937), pp. 269-77.

of railroad facilities; by constant improvements in equipment (especially in the use of larger and more powerful locomotives, and larger, more efficient, and more durable ore cars); and through improvements in track conditions by use of heavier rails, reduction of sharp curves and steep grades, and improvement of roadbeds.

Steam locomotives were first used for hauling iron ore from Lake Superior mines to Lakes ports in 1857 when two 4-wheel locomotives, weighing 25 tons each, were employed to haul 40 tons of ore per train from the Marquette range.[2] By 1897 the largest locomotives in use for hauling ore trains to ore docks had a tractive effort of 26,000 pounds, the train pulled by such a locomotive consisting of thirty 30-ton cars with a total revenue load of 900 tons. In 1929 locomotives with a total weight of 135 tons and a total tractive effort of 67,200 pounds (56,000 pounds of the locomotive itself and 11,200 pounds of the booster) hauled trains of 40 to 50 cars with an ore load of 3,000 tons over the same route; and the modern giant Mallet locomotive, weighing 332 tons with its tender, is capable under favorable conditions of pulling a pay load of 12,000 tons.[3]

The largest cars used especially for ore distribution by railroads in 1889 had a load capacity of 30 tons - which was still the maximum capacity in 1896 - and all cars were made of wood. The first steel ore cars used in ore-dock service, of 40- to 50-ton capacity, were introduced in 1898. By 1924, 93 percent, and by 1937, 95 percent of all ore cars were of steel. Modern, steel drop-bottom ore cars, equipped with air brakes and automatic couplings[4] and mounted on 8-wheeled double trucks, usually hold 50 tons of ore, and many of the latest ones have a capacity of 75 and 85 tons. (See table B-1.) The economy in the use of large cars constructed of steel lies in their higher load-to-deadweight ratio, their lower maintenance and repair cost, and their increased durability - all contributing to lower transportation costs.

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[2] For 2 years prior to 1857 iron ore was transported from Ishpeming to Marquette, Mich., a distance of 15 miles, over what was known as "The Plank Road." This consisted of a railroad in which the rails were wooden stringers covered with flat strips of iron. Over this road 4-wheel wooden cars, containing 3 or 4 tons of ore, were each pulled by a team of mules making one round trip totaling 30 miles a day. Previous to this, ore was usually hauled only in winter, with sleighs and teams. One of the reasons for the discontinuance of team haulage over this road was the "frightful" grades which sometimes resulted in losing control of cars and injuring mules. Strap rails were abandoned soon afterward because of many derailments caused by the ends of the strap irons curling up. See Hearding, *op. cit.*, pp. 174-6; Harris, *op. cit.*, p. 761.

[3] The largest locomotive in iron-ore haulage is used by the Great Northern Railway Company. It is a Mallet weighing 500 tons (full working weight) and is capable of hauling a train of 175 ore cars with a capacity of 75 tons per car, or a total pay load of 13,125 tons. See Vol. 24 (1935) of *Skillings' Mining Review*, No. 10 (July 6); No. 15 (Aug. 10).

[4] Compressed-air brakes and automatic couplings were adopted in the Lake Superior District in the late eighties. (See Hearding, *op. cit.*, p. 176.)

Table B-1.- NUMBER AND SIZE OF RAILROAD ORE CARS USED IN TRANSPORTING IRON ORE FROM MINES TO ORE DOCKS IN THE LAKE SUPERIOR DISTRICT, 1889, 1924, AND 1937

Load capacity of ore car (pounds)	1889[a]		1924[b]		1937[c]	
	Number	Percent	Number	Percent	Number	Percent
Total	11,379	100.0	37,693	100.0	33,502	100.0
14,000-20,000	6,500	57.1	-	-	-	-
32,000	-	-	25	(d)	-	-
40,000-45,000	3,290	28.9	81	0.2	-	-
50,000	1,539	13.5	141	0.4	-	-
60,000	50	0.5	514	1.4	16	(d)
70,000-80,000	-	-	1,251	3.3	388	1.2
100,000	-	-	30,901	82.0	26,440	78.9
110,000	-	-	1,833	4.9	403	1.2
140,000	-	-	-	-	1,200	3.6
150,000	-	-	2,947	7.8	4,747	14.2
162,000	-	-	-	-	250	0.7
190,000	-	-	-	-	58	0.2

[a]Data from *Eleventh Census of the United States: 1890*, "Report on Mineral Industries" (U. S. Dept. Int., Census Office, 1892), pp. 27-8. Represents the ore cars owned by the five railroads shipping ore in the Lake Superior District in 1889.

[b]Data from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps in cooperation with U. S. Shipping Board, 1926), p. 250. Includes all the ore cars of the nine railroads engaged in handling ore to shipside in 1924; 2,780, or 7 percent of the total, were made of wood.

[c]Data from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps, Transportation Ser. No. 1, rev. 1937), pp. 270-1. Includes all the ore cars of the eight railroads engaged in handling ore to shipside in 1937; 1,780, or 5 percent of the total, were made of wood.

[d]Less than 0.1 percent.

Progress in ore transportation was due not only to improvements in equipment but also to more careful organization. Better coordination between mines, railroads, and ore vessels has resulted in more efficient distribution and assembling of ore cars and in more rapid and more orderly movement of loaded cars from mines to upper Lakes docks to meet vessel schedules. "Ore shipped from the Mesabi range in Minnesota is now transported to docks an average distance of 95 miles in five hours, in contrast to sixteen hours in 1920."[5] This saving was accomplished in spite of increasing demands for ore of uniform analysis and the consequent larger importance of more careful ore sampling, analysis, and mixture and of the proper combination of loaded ore cars into trainloads at mine yards and into cargo lots at ore docks.

Although variations in rail freight rates are due to many factors, the declining trend over the long period from 1855 to 1900, as shown in table B-2, reflects the improvement in rail-transportation efficiency.

[5]E. P. Bayer, "Grading Lake Superior Iron Ores," *Engineering and Mining Journal*, Vol. 139, No. 3 (Mar. 1938), p. 50.

Table B-2.- RAIL FREIGHT RATES FROM MINES TO UPPER LAKES PORTS, 1855-1937[a]

(Dollars per gross ton)

Year	From Marquette range to -		From Menominee range to Escanaba	From Gogebic range to Ashland[b]	From Mesabi range to Duluth and Superior	From Vermilion range to Two Harbors[c]
	Marquette	Escanaba				
1855	3.00	-	-	-	-	-
1860	1.09	-	-	-	-	-
1865	1.10	-	-	-	-	-
1870	1.10	1.85	-	-	-	-
1875	0.65	1.25	-	-	-	-
1880	0.55	1.25	-	-	-	-
1885	0.45	0.80	-	-	-	-
1890	0.45	0.70	-	-	-	-
1895	0.32	0.52	0.52	0.52	0.80	0.90
1900	0.25	0.40	.40	.40	0.80	0.90
1905	0.32	0.40	.40	.40	0.80	0.90
1910	0.32	0.40	.40	.80	0.80[d] and 1.00[e]	0.80
1915	0.32	0.40	.40	.55	0.55	0.55
1920	0.65	0.85	.85	.85	1.00	1.00
1925-37	0.54	0.72	.72	.72	0.81	0.81[f]

[a]These rates exclude handling and storage charges at the port. Data are from *Annual Report of the Lake Carriers' Association, 1937* (Cleveland, Ohio: S. P. Mount Printing Co.), pp. 172-3

[b]Via the Chicago & North Western Railway.

[c]From Tower and Soudan.

[d]Rate to Duluth, Minn.

[e]Rate to Superior, Wis.

[f]Except during 1932 and 1933, when the rate was $0.87.

IMPROVEMENT OF ORE-SHIPPING DOCK FACILITIES[6]

The first ore docks in the Lake Superior District - erected at Marquette, Michigan, prior to 1857 - were merely platforms 12 feet above the water, resting on wood poles or piling. At first, ore was shoveled onto these platforms by hand from flat-bottomed cars; later it was dumped onto the platforms from cars having trap-door bottoms. The ore was then shoveled into small boats or wheeled into the larger boats in hand wheelbarrows, with a considerable amount of hand trimming of the ore load in the boats. With these methods a crew of about 50 men required from 4 to 6 days to load a 300-ton boat.

As the volume of ore traffic increased, bigger and better docks were necessary to accommodate larger ore vessels and to increase loading efficiency. The first dock with pockets or bins for storing ore was

[6]A description of ore-shipping dock facilities and their improvement may be found in the following: Hearding, *op. cit.*, pp. 177-8; Harris, *op. cit.*, pp. 761-3; *Transportation on the Great Lakes* (1926 ed.), pp. 252-7; *Transportation on the Great Lakes* (1937 ed.), pp. 277-82; *The Iron Ores of Lake Superior* (7th ed.; Cleveland, Ohio: Crowell & Murray, 1930), pp. 86-7; and "Great Iron Ore Loading Dock System of the Upper Lakes," *Skillings' Mining Review*, Vol. XXVII, No. 18 (Aug. 27, 1938), pp. 1-2.

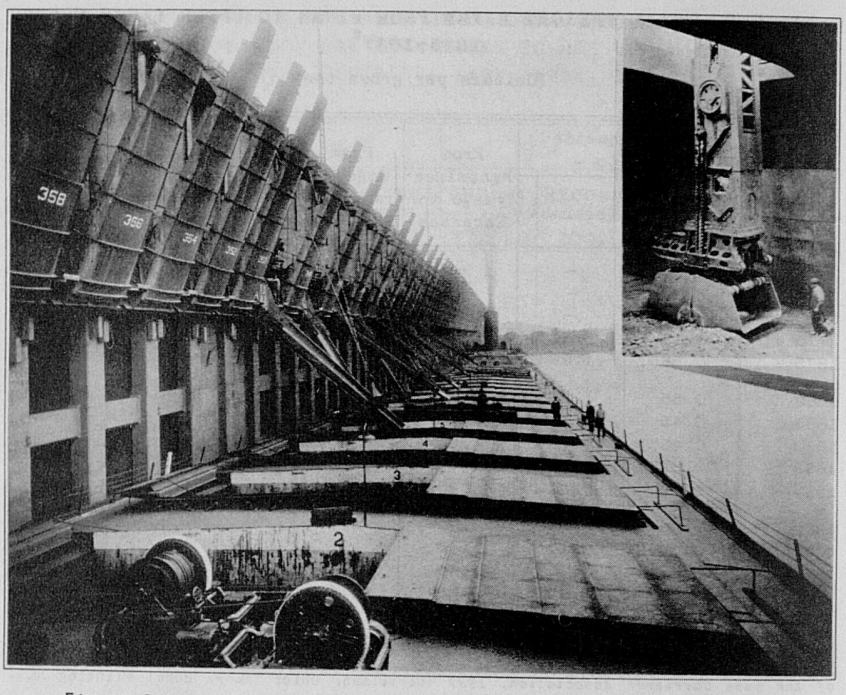


FIGURE B-1.- MODERN METHODS OF LOADING AND UNLOADING ORE VESSELS

The ore freighter is being loaded from a modern ore dock at an upper Lake port. The motor-operated chutes are lowered into the holds of the vessels, and the ore is then loaded by gravity from ore-dock pockets previously filled from steel drop-bottom ore cars run in trains onto the deck of the dock. Modern ore docks, in contrast to those in existence at the turn of the century, are durably constructed of steel and concrete instead of wood; they have been built longer and with chute openings high above the water level to accommodate vessels of large size. The decks have also been raised above the chute openings to enlarge the storage capacity of dock ore pockets.

The inset shows a modern (Hulett) unloader cleaning up the last of a cargo of ore in the hold of a freighter. The operator, who travels with the unloading bucket, may be seen through the opening in the side. A battery of four of these large unloaders, taking up as much as 17 tons in one bite, can unload an ore cargo of 10,000 to 12,000 tons in 3 or 4 hours.

erected in 1857. The ore from the pockets was discharged by gravity through hinged iron chutes let down into the vessel's hold. The deck of this dock was 25 feet above the water level, and the ore pocket or chute openings were $12\frac{1}{2}$ feet above the water line. As ore carriers continued to increase in height and width, higher pocket openings were required and it was necessary to build new docks or to rebuild and enlarge old ones. Also, the deck was raised above the ore bins to provide more storage capacity. By 1883 a dock was built with pocket openings 27 feet, and a deck 47 feet, above water level. The corresponding heights of a dock completed in 1893 were 30 and 57.6 feet respectively; and the largest modern ore docks, the first of which was built in 1919, have an over-all height of 80-84 feet with the pocket openings 40-45 feet above water level.

The increase in the length and capacity of docks corresponded with the increase in the length and capacity of ore freighters which they were designed to accommodate. Thus the lengths of the 15 ore docks in use at the upper Lakes ports in 1889 ranged from 600 to 1,600 feet; the lengths of the 19 ore docks used in 1937 ranged from 920 to 2,304 feet, 6 of them exceeding a length of 2,000 feet. In 1889 the 15 ore docks were equipped with a total of 2,831 pockets with a total storage capacity of 306,000 gross tons; the 19 docks in 1937 had 5,468 ore pockets and a total storage capacity of 1,602,000 gross tons. (See table B-3.)

Table B-3.- CHARACTERISTICS OF IRON-ORE SHIPPING DOCKS IN 1889 AND 1937[a]

Item	1889	1937
Number of ore docks	15	19
Number constructed wholly of wood	15	7
Length (range in feet)	600-1,600	920-2,304
Height, from water to deck above bins (range in feet)	35-47.5	66.5-84
Total number of pockets or bins	2,831	5,468
Total storage capacity (gross tons)	305,750	1,602,250
Total investment in ore docks[b]	$4,000,000	$36,000,000

[a]Data for 1889 from *Eleventh Census of the United States: 1890*, "Report on Mineral Industries" (U. S. Dept. Int., Census Office, 1892), pp. 27-8; for 1937 from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps, Transportation Ser. No. 1, rev. 1937), pp. 278-82.

[b]Estimate of total investment in shipping docks especially built and equipped for handling iron ore. Data for 1937 from "Great Iron Ore Loading Dock System of the Upper Lakes," *Skillings' Mining Review*, Vol. XXVII, No. 18 (Aug. 27, 1938), p. 1.

In 1889 all ore docks were constructed of wood. But, because of the short life of the wooden structures and the increase in the cost of timber, concrete and steel construction has taken the place of wood. The first steel and concrete dock was built in 1908 at Two Harbors, Minnesota, and in 1937 only 7 of the 19 docks were made entirely of wood,[7] 3 were partly of wood and partly of steel and concrete, and the remaining 9 were entirely of steel and concrete.

The improved dock facilities, together with larger ore freighters, greatly increased ore-loading efficiency. The records of one company that has engaged in Lakes transportation of iron ore for more than half a century afford an interesting comparison of the efficiency in loading boats in 1928 as compared with 1899.[8] The average time from arrival

[7]Two of the wooden docks at Escanaba, Michigan, were being razed in 1938. See "Great Iron Ore Loading Dock System of the Upper Lakes," *op. cit.*, p. 2.

[8]Harris, *op. cit.*, p. 763. The record is for vessels owned by the Cleveland-Cliffs Iron Company, which operates the third largest ore-shipping line on the Great Lakes.

to the completion of loading, including delays of all kinds, over the entire water-navigation season of about 8 months, was 54 minutes per 1,000 tons loaded in 1928 as compared with 4 hours and 56 minutes in 1899. The actual loading time of vessels in 1928, in tons per hour, was 1,876 compared with 675 in 1899. The average stay of ore vessels at upper Lakes ports in 1906 was 22 hours and 25 minutes compared with 3 to 4 hours during 1928-37 for vessels loaded with almost twice as much ore[9] (see table B-4), and it is reported that the record speed

Table B-4.- TIME OF ORE VESSELS AT LAKES PORTS AND SIZE OF CARGO, 1883-1937[a]

Year	Average time of vessels in port[b]						Average cargo carried (gross tons)	Largest cargo carried (gross tons)
	Total time at ports		At upper Lakes ports		At lower Lakes ports			
	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.		
1883	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2,324
1892	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3,133
1896	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5,119
1900	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	7,405
1906	58	40	22	25	36	15	5,954	13,333
1916	30	12	9	42	20	30	7,989	13,521
1921	28	25	7	31	20	54	10,147	12,796
1926	20	10	4	36	15	34	7,888	11,497
1928	17	17	3	58	13	19	8,856	14,859
1929	17	10	4	12	12	58	9,339	14,829
1930	16	24	3	33	12	51	9,558	13,838
1931	17	4	3	43	13	21	9,202	12,348
1932	14	46	3	45	11	1	9,133	11,753
1933	14	38	3	53	10	45	8,989	12,452
1934	14	2	3	37	10	25	9,350	13,296
1935	12	45	3	51	8	54	10,139	13,377
1936	18	56	7	38	11	18	9,412	14,651
1937	14	40	4	13	10	27	9,671	15,684[c]

[a]Except as otherwise noted, data are from *Annual Report of the Lake Carriers' Association, 1937* (Cleveland, Ohio: S. P. Mount Printing Co.), pp. 111-5. Data are confined to ore loaded principally at Duluth and Two Harbors and unloaded at ports on Lake Michigan and Lake Erie.

[b]Data for 1906, 1916, 1926, and 1928-36 from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps, Transportation Ser. No. 1, rev. 1937), pp. 37-8.

[c]In the summer of 1938 the steamer "L. E. Block" was loaded with a record cargo of 15,726 gross tons of iron ore at Marquette in 6 hours 15 minutes. The cargo was unloaded at Indiana Harbor in about the same time. See "Great Iron Ore Loading Dock System of the Upper Lakes," *Skillings' Mining Review*, Vol. XXVII, No. 18 (Aug. 27, 1938), p. 2.

n.a. Data not available.

[9]During the period of great depression, 1932-35, ore shipments were so heavily curtailed that there was a minimum of congestion at docks, resulting in fewer delays. In consequence, the average time spent in port was cut materially. (See table B-4.)

in loading an ore freighter was established on September 7, 1921, when the "D. G. Kerr" was loaded at Two Harbors, Minnesota, with 12,508 gross tons of ore in 16½ minutes. The same cargo was unloaded at Conneaut, Ohio, in 3 hours and 5 minutes.[10]

IMPROVEMENT OF WATERWAYS AND ORE VESSELS

Improvements in the water transportation of iron ore on the Great Lakes were equally as great as in loading and unloading; indeed, all of the steps from mining the ore to its manufacture into iron and steel products have been greatly improved, and each advance served both to stimulate and to make possible further improvements all along the line, for all steps are interrelated.

Construction and Improvement of Canals at Sault Ste. Marie

The Lakes transportation of iron ore from the Lake Superior District was made possible by the construction of - and was greatly facilitated by the later improvement of - canals and locks permitting an outlet from Lake Superior to Lake Huron and thence to the lower Lakes ports. The first canal suitable for ore transportation was built by the State of Michigan past the falls and shallow rapids of St. Marys River at Sault Ste. Marie. This canal, completed in 1855 at a cost of one million dollars, was 5,674 feet long and was equipped with two lift locks, each 350 feet long and 70 feet wide. A low-water channel was provided for vessels having a draft of 11.5 feet. The canal was later taken over and rebuilt by the United States Government. Subsequent additions of locks and other improvements in the channels, which widened, lengthened, straightened, and deepened the passages, greatly enhanced their usefulness and enabled them to carry bulk freighters of enormous size. The following list of improvements[11] illustrates the great progress made in facilitating transportation between Lake Superior and Lake Huron:

1870-81.- The United States Government enlarged the original canal, increased its length to 1.6 miles, its width to an average of 160 feet, and its depth to 16 feet. A new lock, called the Weitzel lock, was constructed 100 feet south of the original State canal. This lock was 515 feet long, 80 feet wide in the chamber, narrowing to 60 feet at the gates, and had a depth of 17 feet of water on the sills. (This lock has been out of commission since 1918.)

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[10] *Transportation on the Great Lakes* (1926 ed.), pp. 33-4.

[11] Information obtained from *Transportation on the Great Lakes* (1937 ed.), pp. 2-3; also from *Encyclopedia Americana* (14th ed.; New York: Americana Corporation, 1927).

1887-96.- The original two locks of the State canal were torn down by the Federal Government and were replaced at a cost of $3,000,000 by the Poe lock, 800 feet long, 100 feet wide, with 16.8 feet of water on the sills at low water.

1888-95.- The Canadian Government constructed a large canal 1.4 miles long, 150 feet wide, and with a water depth of 22 feet. This new canal was equipped with a lock 900 feet long, 60 feet wide, and a depth of 17 feet of water on the sills at low water.

1892-1903.- Many millions of dollars were spent during this period in laying out a new and straighter route through Hay Lake and other channels. This was one of the chief causes of the reduction of the freight-ton rate through the United States canal from 13.57 mills in 1882 to 3.53 mills in 1909.

1908-14.- The United States canal above the locks and in the Middle Neebish Channel was widened and deepened, and a new (second) canal was constructed and equipped with the Great Davis (third) lock at a cost of $5,000,000. The width of this canal is 500 feet at the upper entrance, 270 feet at the basin, 108 feet at the lock gates, and 1,000 feet at the lower entrance. The Davis lock is 1,300 feet long, 80 feet wide, and has a minimum depth of 23.3 feet below extreme low water. One result of the opening of this new canal and lock was that the largest size bulk freighters which since 1895 had been using the Canadian canal began again to take advantage of United States facilities.

1912-19.- The fourth or Sabin lock, the same size as the Davis lock, was constructed at a cost of $3,275,000. The Sabin and Davis locks are the longest in the world; their great length - 1,300 feet compared with 1,000 feet for the Panama Canal - enables as many as five ships to go through one lockage.

Present improvements of the St. Marys River provide minimum depths of 20 feet in up-bound channels and 24 feet in down-bound channels, over a minimum width of 300 feet for one-way traffic and of 600 feet for two-way traffic throughout the river. The present dredged areas afford a width of at least 300 feet, increasing at angles and at other critical places up to 1,500 feet.

The two United States canals with their four locks at Sault Ste. Marie are the greatest ship highways in the world. Far more bulk commerce passes through these "Soo" canals during the usual navigation season of 8 months than the combined tonnage borne in a year by the Panama and Suez Canals.[12] In 1937 east-bound cargoes passing the United States

[12]The total freight cargo that passed through the canals at St. Marys Falls in 1937, both east- and west-bound, amounted to 87,633,699 short tons as [*Con.*]

canal at St. Marys Falls reached a total of 70,930,289 short tons, of which 65,575,278 tons, or 92.4 percent, was iron ore. In the 83-year period 1855-1937, an aggregate of one and a half billion tons of iron ore passed through the Soo canals.

Increase in Size and Efficiency of Ore Boats[13]

It is a far cry from the first ore shipment through the Soo canal in 1855 in a wooden schooner carrying only 300 tons, to the modern 600-foot steel freighter with loads of 15,000 gross tons. The 83-year period that has elapsed since that first shipment has witnessed a gradual but spectacular improvement in ore vessels. Wooden boats were replaced by steel freighters; sails, at first supplemented by steam engines, were later replaced entirely by reciprocating steam engines, and the newest ships are being equipped with steam turbines. Meanwhile, as the lengths, breadths, and loading depths of ore vessels have been increased and the general design of construction has been improved, their carrying capacity has grown greatly.

The increase in the size of ore carriers is perhaps the most noteworthy development. Vessels carried ore cargoes of about 550 tons in 1867 and about 1,500 tons in 1872. Practically all of the bulk freight at this time was carried in wooden vessels with sails for added motive power.[14] The first steel ore freighters were introduced in the eighties and were designed to carry ore on a 15.5-foot draft. These vessels had a capacity of 2,500 to 2,800 tons, a length of 320 feet, and a 40-foot beam. By 1898 Lakes ore freighters were built with capacities as high as 6,400 gross tons; by 1904 the capacity of new boats had increased to 10,000 tons; and newly constructed Lakes bulk freighters of the present time can carry loads of 15,000 gross tons.[15] (See table B-5.) The

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[12][*Con.*] compared with a total of 31,481,380 short tons through the Panama Canal and 32,776,000 short tons through the Suez Canal. See *Annual Report of the Lake Carriers' Association, 1937* (Cleveland, Ohio: S. P. Mount Printing Co.), pp. 116-9.

[13]For an account of the growth in the size and efficiency of ore vessels, see A. E. R. Schneider, "Transporting Iron Ore," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929), pp. 766-9; see also *Transportation on the Great Lakes* (1937 ed.), pp. 23-43, 303; see also Charles D. Skillings, "The Development of the Lake Iron Ore Carrier," *Skillings' Mining Review*, Vol. 25, No. 47 (Mar. 20, 1937); see also the *Annual Reports of the Lake Carriers' Association.*

[14]The loading depths of the earliest vessels were restricted to 11-12 feet by the shallow channels in the St. Marys River and in the waterway connecting Lakes Huron and Erie. The depth in the first "Soo" passage was about 13 feet, and in the locks 11.5 feet. The channels were gradually deepened until the water in the present "Soo" locks is 23 to 25 feet deep.

[15]After 6 years of practically complete suspension, shipbuilding on a large scale was resumed in 1936-37. Four 611-foot ore vessels launched in 1937 and early in 1938 for the Pittsburgh Steamship Company embodied construction features and equipment that were far in advance of the previous 600-foot ships. Steam turbine engines and water-tube boilers replaced the usual reciprocating engines and Scotch boilers. The turbines are designed so that the efficiency at half power will be not less than 90 percent of their efficiency at the designed power. The estimated fuel efficiency of the new turbine-equipped boats will be from 50 to 60 percent above that of boats now equipped with reciprocating engines. See *Annual Report of the Lake Carriers' Association, 1937*, pp. 45-8.

Table B-5.- NUMBER AND SIZE OF BULK FREIGHTERS BUILT FOR THE GREAT LAKES TRADE, 1902-35[a]

Year[b]	Number constructed	Over-all length (feet)			Carrying capacity (long tons)		
		Minimum	Maximum	Average	Minimum	Maximum	Average
1902	30	366	440	399	4,800	6,500	5,470
1903	29	374	468	423	4,900	6,900	5,948
1904	7	376	560	463	5,000	10,000	7,128
1905	29	400	569	517	5,000	10,500	8,793
1906	40	400	605	531	6,500	12,000	9,530
1907	40	440	605	517	6,400	12,000	8,937
1908	24	400	569	492	5,500	10,500	8,183
1909	14	374	607	531	5,000	12,000	10,053
1910	20	465	605	538	6,800	12,000	9,570
1911	5	524	617	567	9,000	14,000	11,000
1912	2	524	617	570	9,000	14,000	11,500
1913	5	545	600	581	9,000	12,000	10,900
1914	6	524	625	545	9,000	12,000	9,666
1915	1	550	550	550	10,500	10,500	10,500
1916	8	472	600	574	7,000	12,000	11,062
1917	13	436	600	567	7,000	12,000	11,076
1920	4	600	600	600	13,000	13,000	13,000
1922	4	450	617	554	8,000	14,000	11,500
1923	8	350	600	562	5,500	12,000	11,000
1924	5	576	612	600	11,000	13,000	12,500
1925	9	566	618	586	8,500	13,000	11,911
1926	3	600	633	611	12,500	15,000	13,333
1927	9	400	638	588	7,200	14,000	11,983
1929	4	596	605	601	2,700	12,000	10,140
1930	2	604	605	604.5	7,500	12,000	10,500

[a]Some of these boats were engaged in carrying coal, stone, and grain; the ore freighters are among the largest. Data from *Transportation on the Great Lakes* (U. S. War Dept., Army Engineer Corps, Transportation Ser. No. 1, rev. 1937), p. 43.

[b]No vessels were constructed in 1918, 1919, 1921, 1928, and 1931-35.

trend in the sizes of the cargoes carried by ore freighters is shown in table B-4. The record for largest iron-ore cargoes reveals a constant increase, from the 5,119 gross tons carried by the "Aurania" in 1896 to the 15,726 carried by the "Block" in 1938. Average cargoes carried depend partly upon low water levels during the season (that determine the maximum safe load), and also upon the proportion of small vessels engaged in carrying ore. The cargo average was 9,671 gross tons in 1937 in spite of the number of smaller steamers drawn into service because of the increase in ore shipments, and stands second only to the average of 10,139 gross tons in 1935 when none of the small vessels carried ore.

The lengths of the bulk-cargo carriers increased with their capacities. Up to 1895 the maximum length of Lakes cargo carriers was about 300 feet. In 1902 the maximum length of 440 feet was established with the launching of the "J. B. Cowle." The first 7 vessels of the 600-foot class were built in 1906; by 1924 there were 58 vessels in service, with

Table B-6.- LAKES FREIGHT RATES FOR IRON ORE, 1855-1937[a]

(Dollars per gross ton)

Year	Rate to Lake Erie ports from -		
	Escanaba, Mich.	Marquette, Mich.	Ashland, Wis., and other ports at head of Lake Superior
1855	-	3.00	-
1860	-	2.00	-
1865	-	3.23	-
1870	2.40	3.06	-
1875	(b)	2.87	-
1880	1.77	2.50	-
1885	0.85	1.01	1.20
1890	0.99	1.16	1.26
1895	0.64	0.83	0.96
1900	0.85	0.94	1.05
1905	0.60	0.70	0.76
1910	0.55	0.65	0.70
1915	0.35	0.45	0.50
1920	0.85	1.00	1.10
1924-36	0.525	0.63	0.70
1937	0.60	0.72	0.80

[a]Data are from *Annual Report of the Lake Carriers' Association, 1937* (Cleveland, Ohio: S. P. Mount Printing Co.), pp. 173-4. Data exclude an unloading charge from hold of vessel to rail of vessel. This charge is now 13 cents per gross ton.

[b]None shipped.

over-all lengths varying from 600 to 625 feet and rated capacities of from 12,000 to 14,000 gross tons; and in 1937, 78 vessels in commission had an over-all length of 600 feet or more and capacities in excess of 15,000 gross tons.

The largest modern Lakes freighters, with 12,000 to 15,000 gross tons capacity, on a 21-foot draft, over 600 feet long and with a beam of over 60 feet, carry more cargo per cubic foot displaced than any other type of vessel ever designed. The typical ore carrier has its power plant far aft and its quarters in the extreme forward and after ends. All the space lying between is unobstructed cargo hold, except for intermediate bulkheads forming three or four compartments which serve both to strengthen the ship and to permit the carrying of different grades of ore. Modern ore freighters are also constructed so as to permit the greatest efficiency in loading and discharging cargo. The vessel dimensions are adapted to the dock-loading facilities - the 9- or 12-foot hatches are spaced 12 or 24 feet between centers, and ore-dock discharg-

ing pockets are spaced 12 feet apart. In this way ore can be loaded into all hatches simultaneously.[16]

As Lakes transportation facilities were improved and the volume of the ore traffic expanded, Lakes freight rates were reduced. For example, as shown in table B-6, the freight rates per ton of ore carried from Marquette to Lake Erie ports were reduced from $3.00 in 1855 to $2.50 in 1880, to $1.16 in 1892, and to $0.83 in 1895, when the development of the Mesabi range in Minnesota was well under way.[17]

IMPROVEMENTS AT ORE-RECEIVING DOCKS[18]

Closely paralleling the progress in transportation and in loading facilities at ore-shipping docks at upper Lakes ports was the remarkable and rapid progress in development of unloading facilities at ore-receiving docks at the lower Lakes ports. Fifty or sixty years ago unloading a vessel was a laborious and time-consuming task.

> At the docks, scores of men went into the cargo holds and shovelled every pound of ore or coal by hand, and other legions pushed their straining wheel barrows up the inclines to the docks. Four days of back-breaking toil was required to empty a vessel of average size. Today six hours does the trick with a cargo ten times as great. Where once the waterfront swarmed with men amid a forest of tall masts, now but a scant handful of overalled mechanics may be seen handling the whole cargo of a freighter, with a few lever turns and without any manual labor except in the clean-up of the ship.[19]

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[16] At the opening of the 1937 season, 304 freighters, exclusive of Canadian ships, were engaged in transporting iron ore on the Great Lakes. Their total rated capacity per trip was 2,594,800 gross tons on a 19-foot draft, and the average capacity per vessel was 8,535 gross tons. Later in the year, eight other smaller ships (with a total capacity of 42,800 gross tons) were added to the fleet; these included two ships reconverted from the automobile-carrying type and a few more that never had been in the bulk-freight commerce but had cargo holds into which ore could be poured without excessive delay. See *Annual Report of the Lake Carriers' Association, 1937*, pp. 63-4.

[17] An important factor in the economical transportation of iron ore from Lake Superior mines to consuming centers was the availability of traffic in coal to supply ballast and valuable cargo on the return trips of ore freighters and railroad trains.

[18] For a detailed description of ore-unloading docks and their unloading equipment in recent years, see *Transportation on the Great Lakes* (1937 ed.), pp. 288-95; see also *The Iron Ores of Lake Superior*, pp. 88-9. For a description of ore-unloading facilities in 1889, see *Eleventh Census of the United States: 1890*, "Report on Mineral Industries" (U. S. Dept. Int., Census Office, 1892), pp. 27-9.

[19] Schneider, *op. cit.*, p. 767. The following statement, taken from the *Eleventh Census: 1890*, "Report on Mineral Industries," p. 29, indicates the cost in money and human labor of unloading ore cargoes at a time when unloading buckets lowered into the holds of the vessels were filled by hand shoveling. The examples cited were probably record performances: ". . . . the cost of such handling has been reduced to a minimum. The expense of shoveling the ore into buckets in the holds of vessels varies from 10 to 15 cents per long ton, the rate being controlled by stevedores, while with the improved apparatus at some of the docks this ore in buckets is lifted from the vessel, carried back 350 feet and dumped, at a total cost, including labor, wear and tear, interest, and fuel account reported, of from 1 to 1.5 cents per ton. With 21 men in the hold of a vessel carrying 2,000 long tons of iron ore the entire cargo has been stocked in 17 hours. Other instances are mentioned where with 28 men 2,200 long tons were similarly handled in 15 hours, and 2,100 long tons were handled by 18 men in 17 hours. In [*Con.*]

By the turn of the century, engineering ingenuity had succeeded in perfecting unloading machinery that eliminated the half-ton, hand-filled tub and the wheelbarrow, and present-day docks are equipped with electrically operated, self-filling bucket unloaders which take up from 5 to 17 tons at each grab. In 1929 a dock with a battery of four large machines could unload 50,000 tons of ore in 24 hours,[20] and in 1937 a 10,000-ton vessel could be discharged in 3 or 4 hours.[21] Whereas in 1906 the average stay of ore vessels in lower Lakes ports was 36 hours and 15 minutes, by 1937 this time was cut down to 10 hours and 27 minutes, in spite of the necessity to unload a larger average cargo. (See table B-4.) The ore-unloading record of 4,968 tons per hour was established when the steamer "Henry H. Rogers" discharged 12,009 gross tons of ore in 2 hours and 25 minutes at Conneaut, Ohio.[22] Some of the machines at ore-receiving docks are designed to act as unloaders, distributors, and loaders. Bridge cranes are used in conjunction with them to distribute the ore uniformly over the stock piles or to load railroad cars from stock piles. As far as possible, the ore is shipped direct from the boats to consuming points to avoid the extra expense of handling between ship and storage pile and between storage pile and railroad cars. However, large storage areas are provided at shipside in order that a steady flow of ore to blast furnaces may be maintained after the close of the navigation season.

SUMMARY

The progress, here traced, in transporting an increasing quantity of iron ore from mines to blast furnaces a thousand miles away is all the more remarkable in view of the necessity for delivering ore of the specified analysis required at different consuming points. It seldom happens that a train carries ore of such grade that it may be run straight through from the loading point to the docks without being split up for mixing. Yet the ore vessels must be loaded promptly with a fixed tonnage within a small fraction of 1 percent of the analysis (of iron, phosphorus, silica, and manganese contents) on which it was sold. This objective has been achieved, however, and blast furnaces receive a large

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[19] [*Con.*] using these improved apparatuses in loading from stock piles to railroad cars it is not uncommon to have a gang of men shoveling into buckets and load the ore on cars at the rate of 8 or 9 tons per man per hour."

[20] William G. Mather, "The Iron Industry of the Lake Superior Region," *The Mining Congress Journal*, Vol. 15, No. 10 (Oct. 1929).

[21] *Transportation on the Great Lakes* (1937 ed.), p. 289. An idea of the efficiency of modern unloading equipment may be obtained from the fact that on July 3, 1929, the Pittsburgh and Conneaut docks unloaded 83,000 gross tons of iron ore from seven vessels in 28 hours 20 minutes, gross time. (Data supplied through the courtesy of L. C. Sabin of the Lake Carriers' Association.)

[22] *Ibid.*, p. 35.

and steady flow of ore of requisite grade, despite the great variation in ore deposits and despite also the seasonal nature of iron mining and Lakes navigation. Shipping schedules have been carefully worked out, and control of the flow of ore has been made relatively easy by the use of improved, specialized, and interrelated equipment.

Although data on changes in employment in ore transportation and other handling from mines to smelters are not available,[23] it is clear that technological developments in the past half-century, here reviewed, must have substantially reduced unit labor requirements in this stage of the processes involved in iron production. It should be noted that in iron-ore transportation and handling beyond the mines, in contrast to ore mining, there were no mounting natural difficulties to overcome; each technological advance usually represented a net gain in labor productivity.

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[23] It was estimated in 1928 that about 8,000 men were employed by railroads built to handle iron ore from mines to ore docks and that an additional 2,000 were engaged in boat transportation of iron ore on the Great Lakes. See *Skillings' Mining Review*, Vol. 16, No. 39 (Feb. 4, 1928), p. 1.



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