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PAPERS ON THE CONSERVATION OF MINERAL RESOURCES

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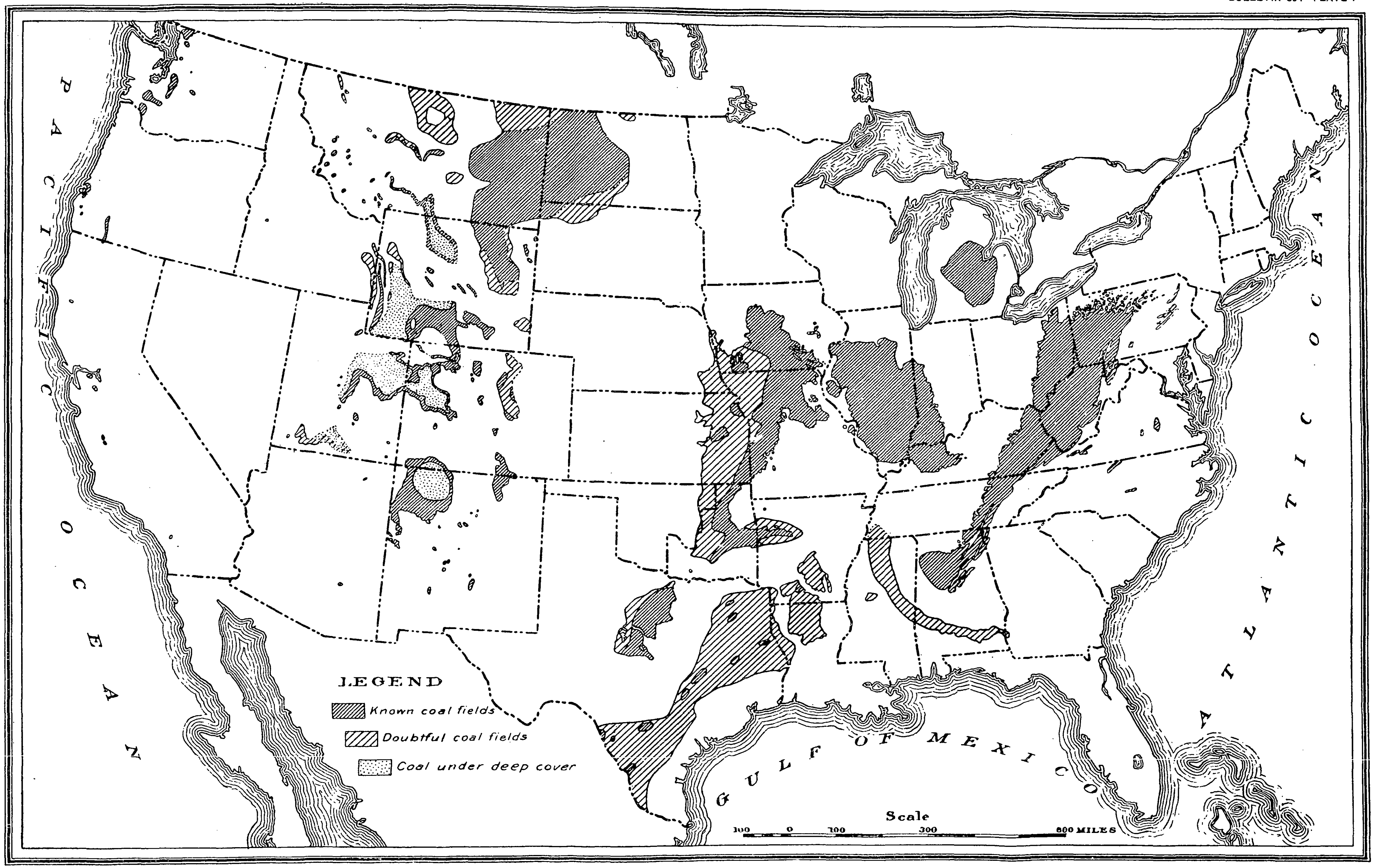
CONTENTS.

ILLUSTRATIONS.

PAPERS ON THE CONSERVATION OF MINERAL RESOURCES.

INTRODUCTION.

This volume is a reprint of selected papers on the conservation of mineral resources, written by members of the United States Geological Survey in response to executive order, for the report of the National Conservation Commission (S. Doc. No. 676, 60th Cong., 2d sess.). Nearly all the information from which these papers are compiled had previously been collected by the Geological Survey in the performance of its regular duties. Since the organization of the Survey the mineral resources of the nation have been the principal subject of its investigations, and the data on which are based the estimates of the reserves of mineral fuels and ores are the results of nearly thirty years of official work. The report on the coal fields is practically a restatement of the information set forth on the coal-field map published in May, 1908, before the appointment of the National Conservation Commission; the other inventories constitute a summation of work in which the authors had been engaged as members of the Survey. The printing of the conservation report has furnished an opportunity to present these reprints in convenient form and, as the demand for the larger report will greatly exceed the edition authorized, this segregation of the papers relating to minerals will prove useful.



DISTRIBUTION OF COAL FIELDS IN THE UNITED STATES.

COAL FIELDS OF THE UNITED STATES.

By Marius R. Campbell and Edward W. Parker.

INTRODUCTION.

According to the estimates prepared by the U. S. Geological Survey, the area underlain by workable coal beds in the United States is 496,776 square miles. Of this total area, 480 square miles contain the entire anthracite coal fields of Pennsylvania. The bituminous coal fields are estimated to be contained in an area of 250,051 square miles. The grade of coal between bituminous and lignite, which is designated by the Geological Survey as "subbituminous," is estimated to be contained within areas aggregating 97,636 square miles, while the areas containing lignite aggregate 148,609 square miles. The coal fields are divided, for the sake of convenience in classification, into six main provinces, as follows (see Pl. I):

1. The eastern province, containing the anthracite coal fields of Pennsylvania and the bituminous coal fields of the Appalachian region, i. e., those of western Pennsylvania, Ohio, Virginia, West Virginia, Kentucky, Tennessee, Georgia, Alabama, and small outlying areas in North Carolina.

2. The interior province, containing the bituminous coal-producing regions of Michigan, Illinois, Indiana, western Kentucky, Iowa, Kansas, Missouri, Oklahoma, Arkansas, and Texas.

3. The Gulf province, containing the lignite areas of Alabama, Mississippi, Louisiana, Arkansas, and Texas.

4. The northern Great Plains province, containing the lignite subbituminous areas of North and South Dakota, eastern Montana, and northeastern Wyoming.

5. The Rocky Mountain province, containing the bituminous and subbituminous areas of western Montana and western Wyoming, Colorado, Utah, and New Mexico.

6. The Pacific coast province, containing the areas of Washington, Oregon, and California.

During the last few years the Survey geologists have worked in all of these coal areas and have also been making careful estimates of the quantity of coal contained in the beds when mining first began. In making these estimates care has been taken to ascertain how much of the supply is easily available and how much is either not available under present mining and market conditions or is available with extreme difficulty. According to these estimates the quantity of coal contained within the known area of the United States when mining first began was 3,076,204,000,000 tons. Of this quantity a little less than two-thirds, or 1,922,979,000,000 tons, is considered as coal that is easily accessible or minable under present conditions, while slightly more than one-third, or 1,153,225,000,000 tons, is considered as non-minable under present conditions or accessible with extreme difficulty. It should be remembered, however, that the quantity of coal given above as easily accessible includes the lignites and subbituminous coals of the Western States, of which approximately 530,000,000,000 tons, while easily accessible, can not be considered available under present conditions or those which may be expected in the near future. This would reduce the original supply of easily accessible and available coal to approximately 1,400,000,000,000 tons.

The area of the different provinces and the quantity of coal contained therein when mining first began are shown in the following table:

Tonnage (short tons), by provinces and accessibility.

[Original coal supply.]

Province.	Area in square miles.	Amount easily accessible.	Amount accessible with difficulty.	Total.
Eastern	70,022	555,634,000,000	8,000,000,000	563,634,000,000
Interior	144,664	406,667,000,000	91,000,000,000	497,667,000,000
Gulf	84,300	13,045,000,000	10,045,000,000	23,090,000,000
Northern Great Plains	103,564	521,793,000,000	459,000,000,000	980,793,000,000
Rocky Mountains	92,396	414,740,000,000	574,280,000,000	989,020,000,000
Pacific coast	1,830	11,100,000,000	10,900,000,000	22,000,000,000
Total	496,776	1,922,979,000,000	1,153,225,000,000	3,076,204,000,000

The distribution of this original supply of coal, according to grades and accessibility, is shown in the following table:

Tonnage (short tons), by grades of coal and accessibility.

[Original coal supply.]

Kind of coal.	Area in square miles.	Amount easily accessible.	Amount easily accessible and available.	Amount accessible with difficulty.
Anthracite and bituminous	250,531	1,176,727,000,000	1,176,727,000,000	505,730,000,000
Subbituminous	97,636	356,707,000,000	216,252,000,000	293,450,000,000
Lignite	148,609	389,545,000,000		354,045,000,000
Total	496,776	1,922,979,000,000	1,392,979,000,000	1,153,225,000,000

The first mining of coal in a commercial way, in the United States, was in what is known as the Richmond basin, a small area in the eastern part of Virginia. Small quantities of coal had been mined here in the latter part of the eighteenth century and it was also in the latter part of the eighteenth and the beginning of the nineteenth centuries that efforts were being made to introduce anthracite coal for fuel purposes. The first actual records of the production of Virginia coal were in 1822, in which year it was reported that 54,000 tons were mined. In 1820 (two years before) 365 long tons of anthracite coal, or 1 ton for each day of the year, had been shipped to distant markets. From these small beginnings of less than a century ago the production of coal has increased until in 1907 the total output of anthracite and bituminous coal approximated 500,000,000 tons. In 1837 the total production of the United States reached, for the first time, a total exceeding 1,000,000 tons, the output being reported from 4 States only—Pennsylvania, Virginia, Kentucky, and Illinois—although Maryland also was producing a small quantity of coal at that time. In 1840 the production amounted to a little over 2,000,000 tons, the output being reported from 13 States. Ten years later, in 1850, the production amounted to 7,000,000 tons; in 1860 it was over 14,000,000 tons; in 1870 over 33,000,000 tons; in 1880 over 70,000,000 tons; in 1890 it approximated 160,000,000 tons; in 1900 it was nearly 270,000,000 tons; and in 1907 it was 480,000,000 tons. The aggregate production to the close of 1907 has amounted to 6,865,097,567 short tons.

Up to the close of 1845 the total production of coal in the United States was 27,700,000 short tons, and since that time the drain on the supply has practically doubled with each decade. The total production to 1845 and decennially since that time has been as follows:

	Short tons.
Up to 1845	27, 677, 214
1846–1855	83, 417, 827
1856–1865	173, 795, 014
1866–1875	419, 425, 104
1876–1885	847, 760, 319
1886–1895	1, 586, 098, 641
1896–1905	2, 832, 402, 746
1906–1907	894, 520, 702
Total	6, 865, 097, 567

It is estimated that for every ton of coal mined and sold, half a ton is lost or wasted, so that the total production of 6,865,097,567 short tons to the close of 1907 represents an exhaustion of 10,200,000,000 tons, or 0.3 per cent of the total original supply, or 0.7 per cent of the coal which is easily accessible and available under the present conditions. The total supply of easily accessible and now available coal left in the ground at the close of 1907 was 1,382,780,000,000 short tons.

Accompanying this statement two charts are presented, one showing the production of coal annually from 1846 to 1907, the other illustrating the average annual production by progressive ten-year periods for the same length of time, the latter chart having been prepared in order to eliminate minor variations due to abnormal conditions. The average annual increase in coal production figured from the average of progressive decades shown on the second diagram is 7.36 per cent, and for the last five progressive decades—1894–1903 to 1898–1907—the rate of increase has been above that average.

DURATION OF SUPPLY.

The total reserve of easily accessible and now available coal is estimated at 1,382,780,000,000 tons. The assumption that a constant output has been reached would be utterly unwarranted. On the other hand, the adoption of the flat rate of annual increase of 7.36 per cent would involve the improbable assumption that the marvelous record of the past and present will be maintained in the future and the production would continue to approximately double every decade. Using the waste allowance, on the basis of this constant rate of increase in production, the 1,382,780,000,000 tons available at the close of 1907 would be exhausted in one hundred and seven years, or by 2015 A. D. Against the use of the flat rate of increase it may well be contended that just as the rate of increase in population tends to diminish, so this rapid increase in per capita consumption of coal can not persist, and a constant annual production will be reached. However, the figures set fifty years ago by statisticians for the probable constant annual production of coal in England have already been exceeded by over 160 per cent.

Mr. Henry Gannett has made an estimate based upon a decreasing rate of increase calculated from twenty-year averages of production. The use of ten-year averages is regarded as unsatisfactory for the reason that one of the decades may consist mainly of a period of prosperity, while the preceding and succeeding decades contain periods of business depression. The twenty-year period, however, is sufficiently long to include a period of prosperity with one of business depression. Taking the four twenty-year periods since 1828, three rates of increase are obtained which show a rapid decrease. The hyperbolic curve computed from these successive rates of increase will indicate the constantly diminishing rate of increase for the successive twenty-year periods. The result obtained by this method is that the easily accessible and available coal will be exhausted about the year 2027, and all coal by the middle of that century. It is recognized that the data upon which this curve has been constructed are few and the curve correspondingly weak. However, in the above estimate all of the data have been given which it is possible to use, and this estimate is believed to represent the best use that can be made of the data at hand.

Inasmuch as America leads the world not only in present production of coal, but also apparently possesses the greatest reserve and certainly is mining coal at much lower cost than any other country, the obvious tendency will be for European countries to look more and more to the United States for their coal supply. Therefore, while our present coal production and consumption are practically equivalent, the export of coal, unless prohibited by federal legislation, must eventually become a factor and increase the coal production in the United States beyond the demands of home consumption. On the other hand, powerful influences will come to bear upon coal production, which favor lengthening the life of the supply. Thus it is to be hoped that with more improved methods in the utilization of coal the increased efficiency per unit may act as a factor in reducing coal consumption, and improved mining methods should likewise decrease the waste percentage. The increased utilization of water power should also tend to decrease coal consumption. Again, as soon as the end appears in sight prices will rise and production diminish, and that progressively. This interference with the law of decreasing increase produced by growing scarcity will, of course, prolong the life of our coal reserves, but at the same time will greatly hamper our industries that depend on this fuel.

With so many indeterminate factors whose importance is realized but can not be measured, prophecy must possess a questionable value.

WASTE IN COAL MINING.

The principal loss or waste attending coal-mining operations is that represented by the quantity of coal necessarily left in the ground as pillars to support the roof. In some cases it is also necessary to leave a foot or more of coal as a part of the roof, because of the unstable character of the material overlying the coal, which itself does not make a good roof. It has also been frequently the case that, where portions of the coal bed have been of inferior quality, only the high-grade coal has been mined and the poorer material left. The coal left as pillars, or as portions of the roof, may be considered a necessary loss, but that which is left because of its inferior quality can not be considered unavoidable waste in any sense, and is frequently of higher grade than coals mined and used in other portions of the country.

Enormous quantities of coal have been lost beyond recovery from the mining of beds lying below, the caving of which, upon the withdrawal of the pillars, has so broken up the overlying strata as to render it impossible to recover the coals contained therein. This has been particularly the case in some of the coal beds of western Pennsylvania, but much improvement has been observed in this regard within later years. Notwithstanding the improvement in this respect it is probable that a large amount of coal will be wasted in the Western States, where a great number of coal beds are closely associated, and also where the intercalated strata are weak, forming poor roofs to the mines.

There are no exact figures as to the actual loss or waste sustained through coal left in the mines in conducting the mining operations, but it has been estimated that it amounts to 50 per cent of the quantity produced and marketed. In some cases, through careful mining and where the conditions are ideal for working, practically all of the contents of the coal beds are recovered. In other cases, particularly when the beds are of enormous thickness, the recovery has not exceeded 30 per cent of the contents. During the earlier days of mining in the anthracite regions of Pennsylvania it was estimated that only 40 per cent of the coal was marketed. This was partly due to uneconomical methods of mining, and partly to the large amount of culm, for which there was at that time no market and which was piled on the ground in unsightly mountains. At the time of the Anthracite Coal Waste Commission, which made its report in 1893, 40 per cent was still considered a maximum recovery. So far as underground workings are concerned, there has been no revolution in the methods employed since that time, but there has been a considerable improvement in the application of those methods, which has resulted in the recovery at the present time of a materially larger proportion of the coal in the ground than was the rule at that date. The earlier methods of mining consisted in leaving comparatively narrow pillars, and in the mining of large rooms the the result was that the pillars were not strong enough to stand the pressure and were crushed beyond recovery. It is now customary to use larger pillars between the rooms, which makes it possible to better control the roof during "robbing" operations and to eventually recover a larger proportion of the contents of the bed.

Material improvements have also been made in the methods of the preparation of coal, so that a much greater proportion of the product hoisted is now being sent to market in merchantable condition. Part of this is due to better and more systematic methods of handling, and part to the saving of small sizes which formerly went to the culm banks. The higher prices of coal and the development of methods for using these small sizes have also made it possible, through washing processes, to rework the small coal formerly thrown on the culm banks, and these are now furnishing several millions of tons of marketable coal annually.

Under present conditions, except in cases where the surface must be maintained, it is estimated that in the Wyoming region of the Pennsylvania anthracite field the recovery for market is from 60 to 64 per cent. In the Lehigh, Mahanoy, and Schuylkill regions the recovery for shipment is estimated at 56 per cent.

When the Anthracite Coal Waste Commission[a] made its report in 1893 the shipments of anthracite had amounted to 820,362,995 long tons, and the total production was estimated to have been 902,000,000 long tons. The commission estimated that for every ton produced, 1½ tons were lost, and the total exhaustion was estimated at 2,255,000,000 long tons. The estimated original contents of the field were 19,500,000,000 tons, and the estimated contents remaining at the beginning of 1893 were 17,245,000,000 tons.

The commission in its report (p. 149) says:

It is to be doubted whether the total coal won when the field shall be abandoned will exceed 40 per cent of the total contents. An estimate on that basis would show the available marketable coal still now in the ground to be as follows:

	Tons.
Wyoming region	1, 859, 000, 000
Lehigh region	477, 500, 000
Schuylkill region	4, 561, 500, 000
In all	6, 898, 000, 000

The amount of coal won at the modern colliery due to improvements in mining methods, in the appliances for handling the coal, and in the utilization of the small sizes shows a decided advance over the earlier years of mining; a still further advance will undoubtedly be made in these directions, and the mining of the small beds, where a larger per cent can be won, will all tend to increase the total. Future estimates for a long time will in all probability show an advance in the total per cent won.

What the commission predicted in the foregoing paragraph has to some extent already been accomplished, from the fact that coal is now being mined from beds that were not considered a part of the available reserves when the commission made its report. In mining methods, as previously stated, there has also been a marked improvement, and the writers are of the opinion that it is safe to assume that since 1893 the 1 ton of coal lost for every ton mined is nearer the actual results than 1½ tons lost for each ton mined, and at this rate the available supply at the beginning of 1893 would have been 8,622,500,000 tons instead of 6,898,000,000 tons. The total production from 1893 to the close of 1907 has amounted to 833,187,445 long tons, which deducted from the estimated available supply of 8,622,500,000 tons would leave as the remaining available supply 7,789,312,555 long tons, it being understood that this is only one-half of the coal left in the ground untouched. What may be done in the future in the way of recovery of coal which is now considered an absolutely necessary waste and lost for all time is, of course, a matter of conjecture.

In the mining of bituminous coal it is estimated that for every ton of coal produced for market one-half of a ton is lost or wasted. The

[a] The members of the commission were Eckley B. Coxe, of Drifton; Heber S. Thompson, of Pottsville; and William Griffith, of Scranton, Pa.

part of this which is represented by the coal left in the mines for pillars, etc., may be materially reduced, but in many cases the recovery of a larger percentage of the coal in the ground can be obtained only by an increased cost of mining; and this in the face of the over-developed properties, keen competition, and low selling prices is incapable of accomplishment at the present day unless there be concerted legislative action by the governments of the several States.

There is another and a serious loss or waste in bituminous coal mining which is, like the culm in the anthracite fields, represented by the slack or fine coal necessarily or unnecessarily produced in mining operations. This is particularly the case when the coal is of the "dry" or noncaking variety which can not be used for coke making or which, because it does not fuse in the fire box, fails to make a satisfactory steam fuel. Many thousands of tons of this "slack" coal are thrown on the ground each year, and much of it is burned in order to prevent it from "cumbering the ground" or adding extra weight above the mine workings. A large part of this waste could be prevented by briquetting, but the process of briquetting adds about $1 per ton to the cost of the fuel, which renders competition with cheap fuel in the shape of raw coal impossible. Two of the causes which lead to the production of unnecessarily large quantities of slack are the excessive use of powder and the practice of "shooting from the solid." These reduce the percentage of large-sized or marketable coal and naturally increase the cost of that portion of the product.

Legislation prohibiting shooting from the solid, which would provide penalties for excessive use of powder, would have as one result a larger percentage of lump coal; and thus in a measure enable operators to assume the additional expense involved in the briquetting of such slack coal as is unavoidably produced.

This legislation is the province of the state governments, and it is not too much to hope that before long laws may be enacted against the accumulation of slack heaps or their useless destruction by burning, and this waste prohibited, as that of natural gas has been in some cases.

The question of the waste in the combustion or utilization of coal does not come within the scope of this paper, but as the manufacture of coke is, in reality, a preparation of the fuel for use, attention may properly be called to the enormous waste resulting from beehive oven practice (the method commonly employed in the United States).

In what is known as the beehive oven (so called because of its similarity in shape to the conventional beehive) the coal is partially consumed, or, more properly speaking, the volatile combustible contents are consumed and all of the valuable constituents of the coal, except the fixed carbon, which is left behind as coke, are wasted.

These wasted constituents consist of gas, tar, and ammonia. In what are known as by-product recovery ovens, however, the process is one of distillation and the by-products of tar and ammonia and all of the gas, except that used for heating the ovens, are recovered and used.

The United States is far behind Germany and other foreign countries in adopting the economies resulting from the coking of coal in by-product ovens. In Germany at the present time little or no coke is made except in retort ovens. The first ovens of this type in the United States were built in 1893 at Syracuse, N. Y. Up to the close of 1907 the total number of this type of ovens completed was 3,892, while the number of beehive ovens in operation in that year was 94,746. The production from the retort ovens was 5,607,899 short tons of coke and that from beehive ovens 35,171,665 tons.

When the economies which may be effected by the use of the retort ovens have been so clearly demonstrated, not only by the plants which have been constructed in the United States, but more emphatically through the much more extensive development of by-product coke manufacture in Europe, the condition in the United States, as shown by the statistics for the last four years, is somewhat difficult to understand. As previously stated, the production of coke in the by-product ovens of the United States in 1907 amounted to 5,607,899 short tons. It was valued at $21,665,157. The total value of by-products obtained in the manufacture of this coke was $7,548,-071, this value and the quantity being distributed as follows:

Value of by-products obtained in manufacture of coke in retort ovens in 1907.

	Quantity.	Value.
Gas .... thousand cubic feet..	20,516,731	$3,130,839
Tar .... gallons..	53,995,795	1,242,530
Ammonia, sulphate or reduced to equivalent in sulphate........ pounds..	125,372,360	3,174,702
Total	....	7,548,071

The gas included in the foregoing statement is the "surplus" not consumed in the coking process and is either sold or used at manufacturing establishments operated in connection with the coke-oven plant. In a few instances where the surplus gas is consumed by the producing companies the quantity is not measured, nor was any value placed upon it in the reports made to the United States Geological Survey. In such cases careful estimates have been made, based upon the average surplus gas obtained from similar coals used at ovens of the same type. The value, similarly estimated, has been placed at from 10 to 15 cents per thousand cubic feet.

The coal consumed in retort ovens in 1907 amounted to 7,460,587 short tons. The quantity of coal used in beehive ovens was

54,485,522 short tons, from all of which the possible by-products are apparently wasted. Assuming that the coal consumed in beehive ovens was of the same average quality as that charged into the retort ovens and that the prices would be not less than 80 per cent of those ruling in 1907, the value of recoverable products which were thus apparently wasted last year amounted to $44,000,000, a sum equal to nearly 80 per cent of the total value of all the coal used in beehive ovens during the year. At the prices which prevailed in 1907 the value of the by-products wasted in beehive coke ovens was a little over $55,000,000.

The value of the by-products from the retort ovens in 1907 was a little more than one-third the value of the coke produced in them.

It should be remembered, however, that beehive ovens are located in the coal-mining regions and that the cost of the coal charged into them represents only a little more than that represented by the expense of mining the coal, whereas in locating by-product recovery plants provision must be made for utilizing or marketing the by-products. It is for this reason that in much the larger number of cases the recovery plants are established near the larger cities and at considerable distances from the mining regions, and the expense of transportation is added to the mining cost of the coal. Hence it is that the value of the coal charged into by-product ovens in 1907 was $15,874,430, or over $2 per ton, while that of the coal used in beehive ovens was $56,956,008, or $1.05 per ton. It must also be remembered that the original cost of installation for a by-product plant is from four to five times that of a beehive plant of equal capacity. These disadvantages are in turn partly offset by the higher percentage yield of coke in the retort ovens and a lower delivery charge on the coke produced. In the case of beehive coke, railroad transportation expense is borne by the coke, while in retort-oven practice all, or nearly all, of the freight charge is borne by the coal..

The total value of the 5,607,899 tons of by-product coke produced in 1907 was $21,665,157, an average of $3.86 per ton. The value of the 35,171,665 tons of beehive coke made in 1907 was $89,873,969, or $2.56 per ton. If we consider that the difference in the value of the by-product coke and beehive coke was due only to the difference in freight charges, then the total value of the entire product of beehive coke made in 1907 would, if made in retort ovens close to the market, have been $135,750,000. On adding to this the value of the by-products that should have been recovered, amounting to $44,000,000 at 80 per cent of the market price in 1907, the total value of the coke and by-products would have amounted to nearly $180,000,000 instead of the value of $89,873,969 for the beehive coke alone. The value of the coal charged into these ovens, however, would have been $108,879,870 instead of $56,956,008. Carrying the hypothesis further, the difference between the value of the coke and by-products if the coal had been coked in retort ovens and the value of the coke alone from the beehive ovens was, say, $90,000,000. From this should be deducted the difference between what the value of the coal would have been at retort ovens and what it was at beehive ovens, i. e., $52,000,000. The remainder ($38,000,000), less the difference in operating expenses, wear and tear, interest on capital, etc., may be considered as approximately the actual net loss in value as the result of beehive coke production compared with by-product coke practice in 1907.

One of the reasons that has been given for the apparent lack of progress in retort-oven building in the last four years is the lack of profitable markets for the by-products of coal tar, and this has contributed to the backwardness of the United States in the development of the chemical industries depending upon coal tar as a raw material, and yet this country is importing coal-tar products to the value of several million dollars annually. It is also well known that the development of the coal-briquetting industry has been retarded because of the lack of assurance of a satisfactory supply of suitable coal-tar pitch for binding material, and there is also an increasing demand for creosoting oils for the preservation of timber.

COAL SUPPLY, PRODUCTION AND EXHAUSTION, BY STATES.

Alabama.—As far as known the earliest record of the existence of coal in Alabama was made in 1834. The first statement of production is contained in the United States Census Report for 1840, in which year the production is given at 946 tons. In 1907 the production was 14,250,454 tons, and the total production from 1840 to 1907 amounted to 164,734,310 short tons, which represented an exhaustion, including the waste in mining, of 247,000,000 tons. The total coal-bearing area of the State is estimated at 14,430 square miles, and the original coal supply is estimated to have been 68,903,000,000 short tons. The exhaustion to the close of 1907 represents a little over 0.3 of 1 per cent, and the production in 1907 was a little over 0.02 of 1 per cent of the estimated original supply.

Arizona.—A small area of 30 square miles in Arizona is estimated to contain 60,000,000 tons of coal, from which there had been no production at the close of 1907.

Arkansas.—As in Alabama, the first production of coal reported in Arkansas was in the census year 1840, when 220 short tons were reported as having been mined in that State. The industry in Arkansas did not develop rapidly during the early years, as the census of 1860 shows a production of only 200 tons, and that of 1880 a total of 14,778 tons. During the last twenty years, however, there has been a marked increase in the production of coal in Arkansas, and the maximum output was reached in 1907, with a total of 2,670,-438 short tons. The total production to the close of 1907 amounted to 23,756,401 short tons, equivalent to an exhaustion of approximately 36,000,000 tons. The estimated original supply of coal in Arkansas was 1,887,000,000 short tons, of which the exhaustion to date represents practically 2 per cent. The production in 1907 was equivalent to 0.15 of 1 per cent of the estimated original supply. The total area in Arkansas which contains workable coal or which may contain workable coal or lignite is estimated to be 7,584 square miles.

California.—The coal fields of California consist of scattered areas, of which, with few exceptions, comparatively little is known. The total workable area is estimated to be 500 square miles, and the original contents of the field 1,000,000,000 short tons. Mining in California had its beginning, according to the records of the state mining bureau, in 1861. The maximum production was reached in 1880, since which time the production has been irregular and has shown a declining tendency, this being due in the last few years to the increased production of oil in the State and its use for fuel purposes. The total coal production to the close of 1907 was 5,030,945 short tons, equivalent to an exhaustion of approximately 7,000,000 tons, or 0.7 per cent of the original supply.

Colorado.—Colorado is one of the Western States which is rich in coal resources. The estimated total area of the coal fields is 17,130 square miles, and the original contents of these fields are estimated to have been 371,770,000,000 short tons. Coal production began in Colorado in 1864, but it was not until 1882 that the output reached as much as 1,000,000 short tons. Since that date there has been a steady increase in production, until in 1907 it amounted to 10,790,236 short tons. The aggregate production to the close of 1907 was 112,-668,336 short tons, of which the equivalent exhaustion has been 169,-000,000 short tons, which represents a little over 0.05 of 1 per cent of the original supply. The production in 1907 was approximately 0.004 of 1 per cent of the original contents of the fields.

Georgia.—The coal fields of Georgia are limited to a small area in the northwestern part of the State, estimated to cover 167 square miles and to have contained, when mining began, 933,000,000 short tons. The census report for 1860 contains the first authentic statement of production in Georgia, and the output in that year is placed at 1,900 short tons. The production of the State in 1907 was 362,401 tons, and the total production to the close of the year was 8,123,696 short tons, representing an exhaustion of 12,000,000 tons. This would still leave in the ground a total of 921,000,000 tons, of which

650,000,000 tons would probably be considered as the available supply, and this, at the rate of production in 1907, would last approximately 1,800 years.

Idaho.—The areas in Idaho known to contain workable coal are placed at 200 square miles, while there are 1,200 square miles which are not known, but which may also contain workable coal. The estimated original contents of the coal fields of Idaho are placed at 600,000,000 tons, from which to the close of 1907 less than 25,000 tons had been mined.

Illinois.—Illinois is the second State in coal-producing importance. The area in Illinois known to contain coal is larger than that of any other State east of the Mississippi River, and if we consider only the known coal areas the coal fields of Illinois cover a wider area than those of any other coal-producing State. The coal-producing area of Illinois is estimated at 35,600 square miles, and the original contents of the fields are placed at 240,000,000,000 short tons. The earliest mention of coal in the United States is contained in the journal of Father Hennepin, a French missionary, who, as early as 1679, reported a "cole mine" on the Illinois River, near the present city of Ottawa. The earliest record of actual mining is that coal was produced in Jackson County in 1810. In 1833 the production is reported to have been 6,000 short tons. In 1907 it was 51,317,146 short tons. The total production to the close of 1907 amounted to 645,868,309 tons, representing an exhaustion of 968,000,000 short tons, from which it appears that the exhaustion to the close of 1907 has been 0.4 of 1 per cent of the total estimated supply. The quantity of coal remaining in the ground at the close of 1907 was 4,664 times the production of that year, or about 2,500 times the exhaustion represented by that production.

Indiana.—The coal fields of Indiana lie entirely in the southwestern portion of the State. They are confined within an estimated area of 6,500 square miles, and contained, when mining first began, 44,169,000,000 tons of coal. Coal mining in Indiana began sometime between 1830 and 1840, and the census of the latter year reported a production of 9,682 tons. In 1907 the production amounted to 13,985,713 short tons, and the total production to the close of that year amounted to 159,440,390 short tons. The exhaustion to the close of 1907 had been 239,000,000 short tons, or 0.54 of 1 per cent of the original supply. Upon these estimates the quantity of coal remaining in the ground in Indiana at the close of 1907 was about 3,000 times the production of that year, and 2,000 times the exhaustion represented by that production.

Iowa.—The coal fields of Iowa are estimated to contain workable coal aggregating 12,560 square miles. To this may be added 5,640 square miles of possible workable coal areas. The original contents of the fields are estimated to have been 29,160,000,000 short tons. From this there has been produced from 1840, when mining first began, to the close of 1907, a total of 141,608,792 short tons, representing an exhaustion of 212,000,000 short tons. The quantity of coal still available at the close of 1907 was 28,948,000,000 short tons. At the rate of production in 1907, in estimating half a ton lost for every ton mined, this supply would last 2,550 years.

Kansas.—The areas in Kansas known to contain workable coal are placed at 3,100 square miles, although in addition to this there are 15,780 square miles which may contain workable coal. The estimated supply, when mining first began, is placed at 7,022,000,000 short tons. From this there has been produced from 1869 (the year of earliest production) to the close of 1907 a total of 91,176,204 short tons. This represents an exhaustion, including loss in mining, of about 136,000,000 short tons, from which it would appear that about 1.9 per cent of the original supply has been exhausted. The production in 1907 was 7,322,449 short tons, equivalent to an exhaustion of 10,000,000 short tons, which would indicate, at the rate of production in 1907, that the known coal supply of Kansas would last approximately 700 years.

Kentucky.—Kentucky is the only one of the coal-producing States which has within its borders areas belonging to two of the great coal fields. The eastern counties of the State are underlain by the coal beds of the great Appalachian system, while the southern limits of the central or eastern interior field are found in the more northern counties of the western part of the State. The eastern areas contain 10,270 square miles, the contents of which, when mining began, are estimated at 67,787,000,000 short tons. The western areas contain 6,400 square miles, the original contents of which are placed at 36,240,000,000 short tons. The total estimated original supply of the State was therefore 104,027,000,000 short tons. Mining began early in the second quarter of the nineteenth century, and it is estimated that from 1829 to 1835 the production ranged from 2,000 to 6,000 tons a year. The production in 1907 was 10,753,124 short tons, and the total production to the close of the year was 122,404,574 short tons, which represents an exhaustion of 184,000,000 short tons, or 0.18 of 1 per cent of the original supply. The quantity of coal left in the ground at the close of 1907 would then be 103,844,000,000 tons, of which approximately 67,000,000,000 short tons would be considered available, or, in other words, the supply at the close of 1907 was 6,700 times the production in that year.

Maryland.—The coal fields of Maryland are confined to a limited area in Allegany and Garrett counties in the western part of the State. This area has an extent of 455 square miles and the original supply is estimated to have been 8,044,000,000 short tons. Mining began early in the nineteenth century, and shipments were made down the Potomac River in 1830. The first shipments by railroad were made in 1842, in which year 1,708 tons were shipped over the newly built Baltimore and Ohio Railroad. In 1907 the production amounted to 5,532,628 short tons, and the total production to the close of that year aggregated 147,606,548 short tons, equivalent to an exhaustion, including waste, of 221,000,000 tons, or not quite 3 per cent of the original supply. The supply still remaining at the close of 1907 was 7,823,000,000 short tons, 1,422 times the production and 948 times the exhaustion represented by the production of that year.

Michigan.—The coal fields of Michigan are the only ones within the drainage basin of the Great Lakes. They occupy an area of approximately 11,000 square miles and are estimated to have contained when mining first began a total of 12,000,000,000 short tons of coal. Although coal mining has been carried on in Michigan for about seventy years, it is only a little more than a decade since it became of any importance as an industry, the production exceeding a million tons a year for the first time in 1901. The total production to the close of 1907 was 13,842,943 short tons, which, including waste, represents an exhaustion of 21,000,000 short tons, or 0.175 of 1 per cent of the total original supply. The production of Michigan in 1907 was 2,035,858 short tons. The supply remaining at the close of that year was, according to the best estimates, 11,979,000,000 short tons, of which 7,986,000,000 tons would be considered as available. This is equivalent to 3,900 times the production of 1907.

Missouri.—The original coal supply of Missouri is estimated to have been 40,000,000,000 short tons, included within an area of 23,000 square miles. The production of the State to the close of 1907 had amounted to 97,618,106 short tons, representing an exhaustion of approximately 146,000,000 tons, or 0.36 of 1 per cent of the original supply. The production in 1907 was 3,997,936 short tons, which is equivalent to an exhaustion of approximately 6,000,000 tons. The supply remaining at the close of 1907 is about 6,500 times the exhaustion created by the production in that year.

Montana.—Montana's scattered coal fields, known to contain workable coals, aggregate 34,067 square miles, while the areas which may contain workable coal, but which are not well known, amount to 17,575 square miles. The original contents of these coal fields are estimated to have been 303,060,000,000 short tons, from which there have been mined to the close of 1907 approximately 24,740,000 tons, representing an exhaustion of 37,000,000 tons, or 0.012 of 1 per cent of the original supply. The production in 1907 of a little over

2,000,000 tons is equivalent to an exhaustion of about 3,000,000 tons, and the coal left in the ground was 100,000 times that exhausted.

New Mexico.—The coal fields of New Mexico aggregate a total area of 18,335 square miles, and the original supply is estimated to have been 163,780,000,000 short tons, from which there had been produced to the close of 1907 a total of 22,325,432 short tons, representing an exhaustion of 33,000,000 tons, or 0.02 of 1 per cent of the original supply. The production in 1907 (2,628,959 short tons) is equal to nearly 12 per cent of the entire production of the coal to the close of that year, while the coal left in the ground is nearly 65,000 times the production in 1907, and over 40,000 times the exhaustion represented by that production.

North Carolina.—Two small areas of Triassic age contain all the coal known to exist in North Carolina. The total area is about 60 square miles, and the original contents of the field are estimated at 200,000,000 short tons. These areas have never been worked to any large extent, and the total production to the close of 1907 was less than half a million tons.

North Dakota.—Although the coal fields of North Dakota are of wide extent, the coal itself is all of lignitic character and of little commercial value at the present time. The total areas supposed to contain workable lignite are placed at 35,500 square miles and the original contents have been estimated at 500,000,000,000 short tons. The production, particularly considering the large supply, has been very small, the total exhaustion to the close of 1907 having amounted to only 4,000,000 tons.

Ohio.—Compared with the supply of coal originally contained within the coal fields of Ohio, the rate of exhaustion has been greater than that of any other State in the Appalachian system, with the exception of Maryland. The estimated original supply contained within an area of 12,660 square miles was 86,028,000,000 short tons. The first record we have of the production in the State is in the year 1838, when 119,952 short tons of coal were mined. Ohio's output was at that time exceeded only by the production of Pennsylvania anthracite and bituminous coal from the Richmond basin. From 1845 to 1875 Ohio ranked second among the coal-producing States. In 1876 it was surpassed by Illinois, and since 1896, when it was surpassed by West Virginia, it has ranked fourth among the coal-producing States. In 1907 Ohio contributed 32,142,419 short tons of coal to the total product of that year. The total output of Ohio mines from 1838 to the close of 1907, a period of seventy years, has amounted to 492,769,358 short tons, representing an exhaustion of 739,000,000 tons, or something less than 0.9 of 1 per cent of the estimated original supply. The production of 1907, which was a little less than 7 per cent of the production to the close of that year, was equivalent to an exhaustion of about 48,000,000 tons. Deducting from the original supply the exhaustion at the close of 1907, there would still be available on January 1, 1908, 85,980,000,000 tons, or nearly 2,000 times the production in 1907.

Oklahoma.—All of the coal in Oklahoma is contained in that portion of the State which was formerly known as the Creek, Cherokee, and Choctaw nations of Indian Territory. The total area underlain by workable coal is estimated to be about 10,000 square miles, and the original contents are estimated to have been 79,278,000,000 tons. Mining did not begin in Indian Territory until comparatively late, the first production reported having been in 1880, when 120,947 short tons were produced. The industry has progressed rapidly, however, and the production in 1907 amounted to 3,642,658 short tons. The total production to the close of 1907 was 39,845,015 short tons, representing an exhaustion of approximately 60,000,000 tons. The quantity of coal left in the ground in Oklahoma at the close of 1907 was 13,000 times the exhaustion represented by the production in that year.

Oregon.—As far as known the earliest record of coal production in Oregon was in 1880, when the output amounted to 43,205 short tons. In 1907 Oregon's production was 70,981 short tons, and the aggregate production from 1880 to the close of 1907 was 1,790,392 tons, which represents an exhaustion of 2,700,000 tons. The total area in the State containing workable coals is estimated at 230 square miles and the original supply at 1,000,000,000 short tons.

Pennsylvania.—The supplies of anthracite coal in Pennsylvania are discussed elsewhere in this paper. (See p. 13.) The bituminous areas in the western portion of the State are estimated to have an extent of 14,200 square miles and to have contained, when mining first began, 112,574,000,000 short tons. The development of the Pennsylvania bituminous coal fields did not begin until about twenty years after anthracite mining was established as an industry, the first production having been reported in the census year 1840, when 464,826 short tons were mined. Up to 1897 the production of anthracite coal in Pennsylvania exceeded that of bituminous, but in 1898 the bituminous production took the lead and has continued to lead since that date. In 1907 the production of bituminous coal exceeded that of anthracite by nearly 80 per cent, and as indicative of the extent to which the bituminous coal-mining industry of Pennsylvania has grown it may be stated that the production in 1907 was nearly three times that of 1897, only ten years before. The total production of bituminous coal in Pennsylvania to the close of 1907 was 1,846,069,253 short tons, which was equivalent to an exhaustion of 2,760,000,000 tons, or 2.5 per cent of the original supply. The exhaustion represented by the production in 1907 was 225,000,000 tons. The supply remaining at the close of 1907 was 109,804,000,000 tons, or 492 times the exhaustion represented by the production of that year.

South Dakota.—The northwest corner of South Dakota contains the southern extension of the North Dakota lignite beds, and it is estimated that about 6,000 square miles of this territory may contain workable lignites. The contents are estimated at 10,000,000,000 short tons, and these are practically untouched.

Tennessee.—The coal fields of Tennessee are contained in a narrow strip in the eastern counties of the State, where the Appalachian province crosses the State in a northeast-southwest direction. Mining began sometime between 1830 and 1840, and the census for the latter year reported a production of 558 tons. Coal mining did not, however, develop into an important industry in Tennessee until after the close of the civil war, and it was not until 1883 that the production reached as much as 1,000,000 tons annually. Since that time it has increased with notable regularity, until in 1907 the production amounted to 6,810,243 short tons. The total area of bituminous coal in the State is estimated at 4,400 square miles, and the total original supply at 25,665,000,000 tons. The total production to the close of 1907 amounted to 84,304,601 short tons, representing an exhaustion of approximately 126,000,000 tons, or about 0.5 of 1 per cent of the original supply. The exhaustion represented by the production in 1907 was approximately 10,200,000 tons, and the supply left in the ground at the close of the year was equal to 2,500 times this exhaustion.

Texas.—The known bituminous coal fields of Texas are estimated to contain 8,200 square miles, and the exploited lignite fields 2,000 square miles. In addition to this there are 5,300 square miles which may contain workable bituminous coal and 53,000 square miles which may contain workable lignite. The estimated contents of the bituminous coal fields when mining first began in Texas were 8,000,000,000 short tons, and of the lignite fields 23,000,000,000 short tons. The exploitation of both the lignite and the bituminous areas is of comparatively recent date, no production having been reported from Texas prior to 1884, and it was not until 1901 that the output reached as much as 1,000,000 tons. The production to the close of 1907 was 14,444,948 short tons, representing an exhaustion of 22,000,000 tons, or 0.07 of 1 per cent of the original supply.

Utah.—Utah's coal fields are contained in scattered areas aggregating 15,130 square miles. The quality of the coals ranges from subbituminous to anthracite. The estimated original supply was 196,458,000,000 short tons, from which the exhaustion, including waste, at the close of 1907, was 28,000,000 short tons, indicating that there were still remaining in the ground 196,430,000,000 tons, or a little more than 100,000 times the production of 1907.

Virginia.—The Richmond basin in Virginia, where coal mining in the United States was first carried on, contains 150 square miles. Another small area in Montgomery County contains 200 square miles of coal-productive territory, but the principal regions are in the southwestern corner of the State, which is crossed by the Appalachian system. The portion of the Appalachian coal field in Virginia is estimated to be 1,550 square miles. The original supply has been placed at 22,500,000,000 short tons. From this there had been produced at the close of 1907 a total of 57,229,152 short tons, representing an exhaustion of 86,000,000 tons. The production in 1907 was 4,710,895 short tons, equivalent to an exhaustion of a little over 7,000,000 tons, so that the coal left in the ground in Virginia at the close of 1907 was 2,000 times the exhaustion represented by the production of that year.

Washington.—Washington's coal supply is contained within a number of areas that are scattered over the State and aggregate approximately 1,100 square miles. The estimated original supply was 20,000,000,000 short tons, and while mining began there as early as 1860, the total production to the close of 1907 was only 43,108,697 short tons, of which nearly 50 per cent was produced within the last seven years. The exhaustion represented by the production to the close of 1907 was 64,000,000 short tons, which is equivalent to about one-third of 1 per cent of the original supply. The quantity of coal still in the ground at the close of 1907 was estimated to be 19,936,000,000 short tons, equivalent to 5,400 times the production of 1907 and 3,600 times the exhaustion made by that output.

West Virginia.—The total area containing workable coal in Virginia is 17,000 square miles, and the original supply when mining first began was 231,039,000,000 tons. West Virginia was not admitted as a State until 1863, in which year the production amounted to 444,648 short tons. The quantity of coal mined prior to that time, in the portion of Virginia which afterwards became West Virginia, was not sufficient to materially affect the total output. For a number of years West Virginia has been third among the coal-producing States, and in 1907 the production amounted to a little over 48,000,000 tons. The aggregate production to the close of 1907 was 434,198,539 short tons, equivalent to an exhaustion of 650,000,000 tons. At the beginning of 1908 there still remained available in the coal fields of West Virginia 230,389,000,000 short tons, nearly 4,800 times the production in 1907, or 3,200 times the exhaustion represented by the 1907 output.

Wyoming.—The estimated original coal supply of Wyoming is larger than that credited to any other coal-producing State, with the exception of North Dakota. In the latter State, however, the entire supply is lignite, while in Wyoming the coals are of subbituminous or of bituminous character. The total area which may contain workable coals has been estimated at 50,793 square miles, and the contents of this field, when mining first began, at 424,085,000,000 short

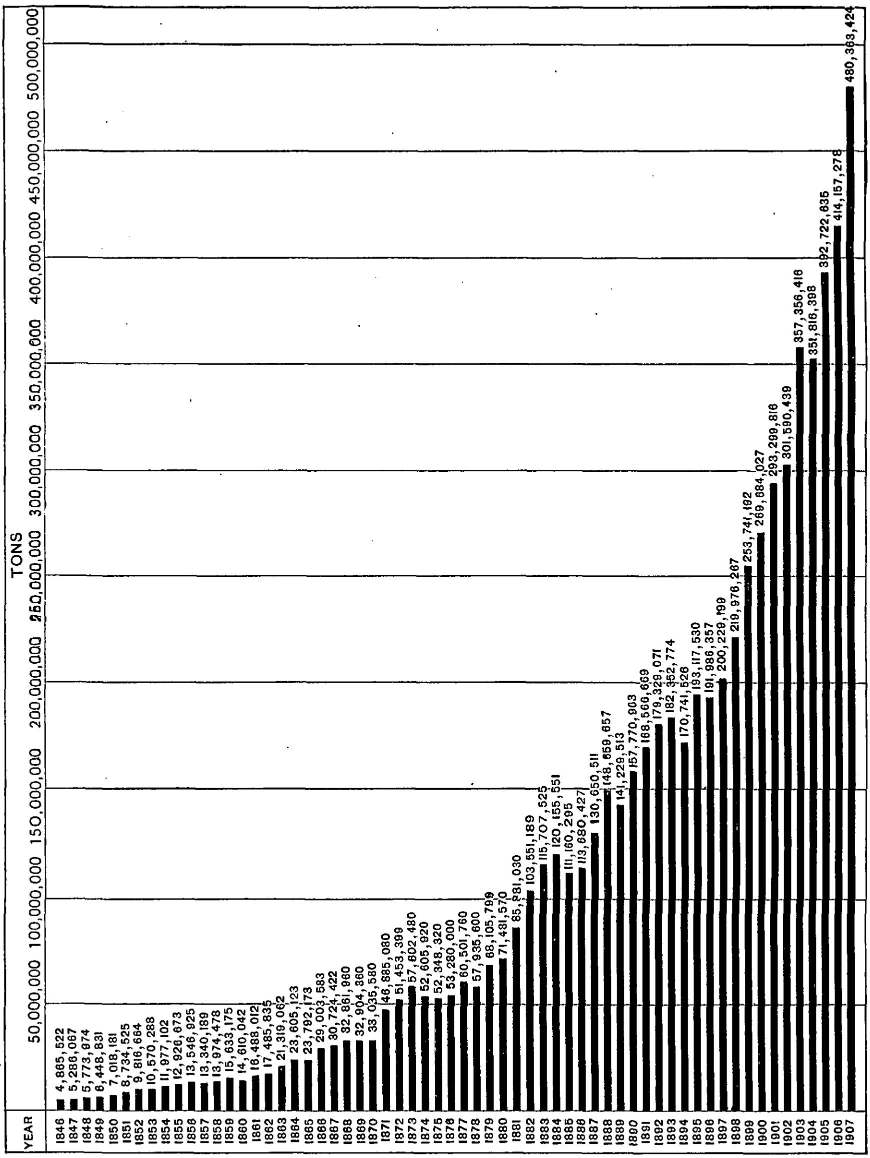


FIGURE 1.—Chart showing production of coal in the United States from 1846 to 1907.

tons. In comparison the aggregate production at the close of 1907, which was 77,818,765 short tons, appears insignificant. The total exhaustion of the beds to the close of 1907 amounted to 116,000,000 short tons, or 0.027 of 1 per cent of the total estimated supply.

ESTIMATES OF FUTURE COAL PRODUCTION.

By Henry Gannett.

The Geological Survey estimates the amount of coal remaining in the ground to be 3,147,043,000,000 tons, of which about two-thirds is easily obtainable, the other third being of indifferent or poor quality and difficult of mining.

In nearly a century of mining about one-third of 1 per cent of the supply has been taken out of the ground. The production during the year 1907, which was more than 480,000,000 tons, was much larger than in any previous year.

The Geological Survey also estimates that in mining practice about 1 ton of coal is lost for every 2 tons won, either by leaving it in the ground or in breaking and transporting.

In order to reach even an approximate idea of the length of time that this coal supply will last, it is necessary in the first place to estimate the probable annual production in the future. That it will increase beyond the present maximum goes without saying, but at what rates and for how long a period will the increase continue are questions whose solution can only be guessed. Unfortunately we have very few data upon which to build. The rate of yearly increase of production is very irregular, so irregular that no conclusions can be drawn from it. It is impossible to construct from it a smooth curve which might be projected into the future. Even if ten-year averages be taken, and the rate of progress be thus obtained per decade, the result is very unsatisfactory, for the reason that one of the decades may consist mainly of a period of prosperity while the preceding and succeeding decades may contain periods of business depression. It is necessary, therefore, in order to obtain rates of increase which are fairly comparable with one another that we take the rate of production for periods sufficiently long to include a period of prosperity with one of business depression, i. e., twenty years. This has been done with the following results, expressed in terms of millions of tons, each the production of twenty years, with percentages of increase:

Production of coal and rate of increase, by twenty-year periods, 1828 to 1907.

Years.	Production.	Per cent of increase.
	Millions of tons.	
1828-1847	37.3	....
1848-1867	306.0	720
1868-1887	1,451.0	374
1888-1907	5,068.0	249

We have here three rates of increase and they show a very rapid decrease. It would, of course, be folly to assume that the latest rate of increase, 249 per cent, is to continue indefinitely or even at all. There is every indication that the next twenty years will show a great diminution; indeed, at the present rate of increase of production, all the coal would be exhausted before the end of the present century.

The normal curve formed by rates of increase is a hyperbola—that is, if population or production, etc., is not interfered with by extraneous influences, it tends to increase in a constantly diminishing ratio, but never ceases to increase, and the successive rates of increase when plotted to scale form a hyperbolic curve. The equation of this curve, referred to its asymptotes, is $(x - a)\ (y - b) = c$. We have three points on this curve, i. e.:

$$x=1 \qquad y=720$$
$$x=2 \qquad y=374$$
$$x=3 \qquad y=249$$

x being periods of time, in this case twenty-year intervals, and y being the corresponding per cents of increase.

Using these values in the above equation, we obtain for the constants:

$$a= 13$$
$$b= 17$$
$$c=833$$

Substituting these values of the constants in the equation, and giving x successively values of 4, 5, 6, etc., the following values for y, the per cents of increase, are obtained, as shown below, with the resulting amount of coal production in each successive twenty-year period:

Estimated production of coal and rate of increase, by twenty-year periods, 1908-2067.

Years.	Per cent of increase.	Production.
		Millions of tons.
1908-1927	185	21,375
1928-1947	145	52,369
1948-1967	119	114,688
1968-1987	100	229,376
1988-2007	85	424,346
2008-2027	74	738,362
2028-2047	65	1,218,297
2048-2067	58	1,924,909

The production for the double decade 2048-2067 is estimated at the enormous rate of 274 tons (including waste) for every man, woman, and child then in the country, or, excluding waste, 183 tons per capita.

As is seen above, the easily accessible coal may be exhausted about the year 2040, and all coal about the middle of that century; i. e., ten years later.

It must not be supposed, however, that this programme will be carried out. In the first place, the data upon which this curve has been constructed are very few, and the curve is correspondingly weak. They are, however, all that we possess and the foregoing is probably the best way to use them.

In the future, powerful extraneous influences will come to bear on coal production, and all, as far as can be foreseen, except possible exports, are in favor of lengthening the life of the supply.

As soon as the end appears in sight the price will rise and production diminish, and that progressively. This interference with the law of decreasing increase, produced by growing scarcity, will of course prolong the life of our coal reserves, but at the same time will greatly hamper our industries dependent on this fuel.

Again, the development of water power will prove another disturbing factor which will prolong the life of our coal supply. To a great extent, city heating and lighting and power for manufacturing, and transportation will in the near future be furnished by water power. It is estimated that in round numbers 30,000,000 horsepower are going to waste in our streams to-day, most of which can and will be utilized, replacing coal. If all the latent water power in the country were harnessed within the next twenty years, it would probably prolong the life of the coal supply by about eighty years.

Furthermore, the economies to be introduced in mining and handling coal will result in saving a large part of the present waste. If the production and transportation were relieved of all waste within the next twenty years, the coal supply would last twenty years longer.

THE PETROLEUM RESOURCES OF THE UNITED STATES.

By DAVID T. DAY.

EXTENT OF THE PETROLEUM FIELDS.

This report deals with the petroleum fields of the United States as known at present; that is, it is limited to the petroleum pools actually developed, or what is known as "proved territory."

LOCATION.

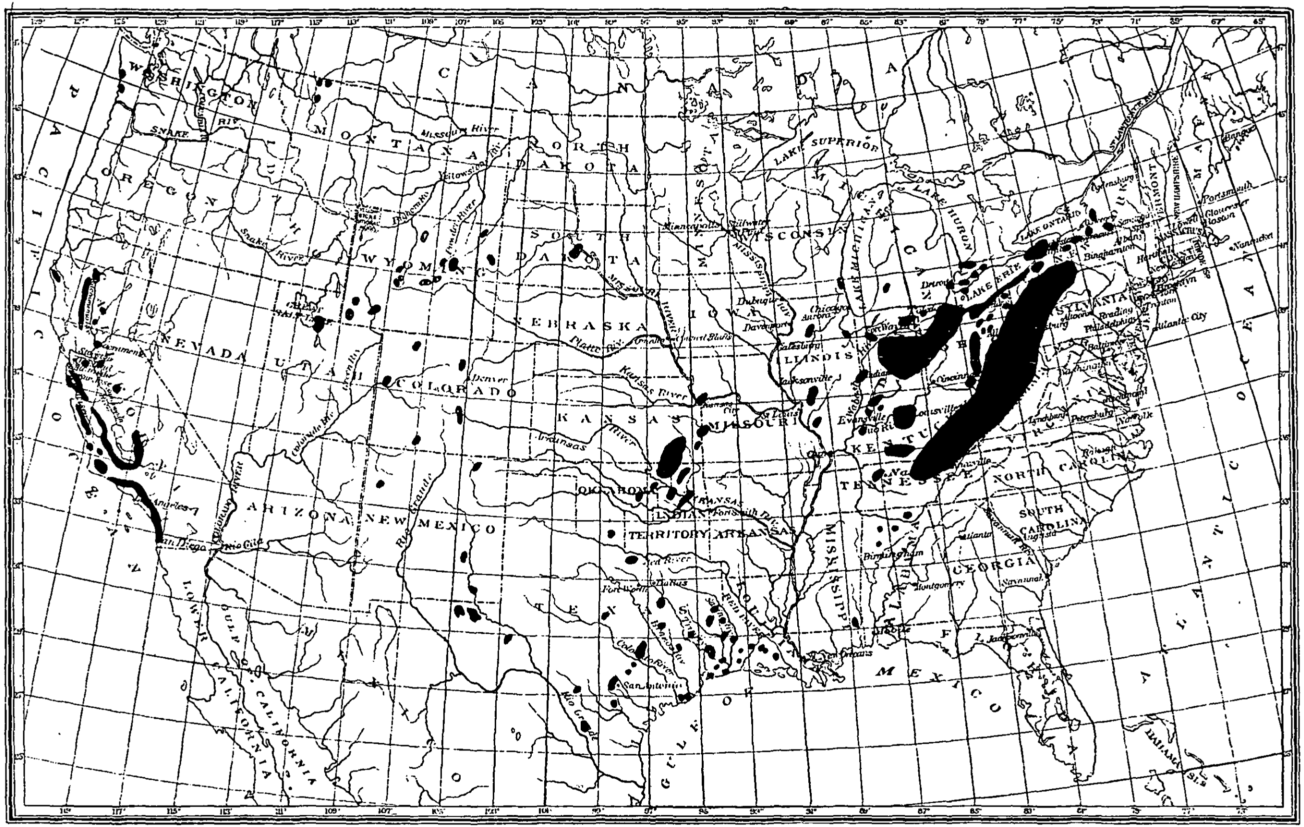
The areas where petroleum is known to occur at present are shown on Plate II.

Appalachian.—Petroleum is unknown and improbable east of the Allegheny Mountains. Parallel with their western flank the Appalachian belt extends from western New York to Tennessee. It crosses western Pennsylvania, and there petroleum was first found in large quantity. The supply in Pennsylvania is rapidly becoming exhausted. It has declined to one-third of its highest rate of production. This high-production mark was only seventeen years ago. The Appalachian field continues across West Virginia and includes the eastern edge of Ohio. Farther south moderate supplies have long been known, and they are still being developed in Kentucky and Tennessee.

"Petroleum" in this report means crude petroleum, as it comes from the earth; that is, before it has been refined. The word "oil" refers to products obtained from petroleum.

The petroleum of this field (known generally as Pennsylvania petroleum) differs essentially from that of the other fields in the United States. It is notably different from any other petroleum thus far found in the world. It is most easily converted into lamp oil, and yields the greatest percentage of this product. The lamp oil is, in fact, the finest yet produced—much better than any other except the products from western Ohio and Indiana, and the petroleum from this latter field costs more to refine.

Farther south, in Kentucky and Tennessee, the product is progressively poorer, but is much better than Russian or any other of the foreign products with which it comes in competition.



DISTRIBUTION OF PETROLEUM AND NATURAL GAS FIELDS IN THE UNITED STATES.

Lima-Indiana.—The second great field in historical development covers a considerable portion of northwestern Ohio and eastern Indiana, and small isolated pools of petroleum of the same general character are found elsewhere in Indiana. This petroleum is more uniform than the Pennsylvania varieties. It contains, quite uniformly, less gasoline and less lamp oils, and the presence of organic sulphur compounds results in an average of one-half of 1 per cent of sulphur, which can be removed only by ingenious and comparatively costly refining processes.

Illinois.—In Illinois, near the eastern edge, a strip of territory some 30 miles long and of irregular width, averaging about 6 miles, is yielding a comparatively enormous quantity of petroleum. It is freer from sulphur than the Lima-Indiana variety, and occasionally contains sufficient asphalt to ally it to the petroleum from the next field to the west, the Mid-Continent field.

Mid-Continent.—This comprises the pools in Kansas and Oklahoma, and must eventually include, for statistical purposes, the pools in northwestern Louisiana and northern Texas. The yield from this field within the last two years has been so large as to greatly disturb the industry, on account of the difficulty of providing sufficient refining and transportation facilities. This petroleum differs from Pennsylvania petroleum in frequently containing small amounts of asphalt, and also in containing hydrocarbons less stable in their action toward the chemicals used in refining them. Nevertheless, it has proved possible to obtain good yields of perfectly satisfactory products covering the entire range from gasoline to paraffin wax. Some of the petroleum of this field contains sufficient water and other foreign materials to complicate the matter of giving it a just valuation, and also to add to the difficulty of the refining processes.

In the Mid-Continent field the Glenn pool, located a few miles south of Tulsa, Okla., is a good illustration of the uncertainties of petroleum production. A well drilled in 1905 happened to be located a few feet within the limits of this pool. Had it been located slightly farther to the east the field would not then have been discovered, but the very considerable flow from this well caused more than usual excitement, and nearly all of the wells drilled to the west proved good producers. The wells produced 1,000,000 barrels from 1,000 acres of ground within the year 1906. Well drilling was so rapid, in fact, that the pool reached its maximum production thirteen months after the discovery of the first well, and from that time the production declined almost as rapidly as it had increased, until the decline was arrested by cleaning out the wells, and afterward, also, shooting them with nitroglycerine. The transportation companies could not keep up with such rapid development, and perhaps 1,000,000 barrels of petroleum was wasted on the ground within two years.

Gulf.—For many years the escape of petroleum and natural gas to the surface has been noted at many points in Texas and in southern Louisiana. This led to the drilling, in 1901, of a well at Spindle Top, near Beaumont, Tex., from which probably more than 500,000 barrels of petroleum flowed before the well could be checked. The field was soon extended to Jennings and Welsh, and later to Anse la Butte, in Louisiana. Other wells were rapidly drilled (Pl. III), resulting in a large addition to the petroleum product of the United States. This petroleum contains a large percentage of asphaltum and relatively small amounts of gasoline and lamp oils, and therefore offers little temptation to the refiner. It is also handicapped by the presence of sulphur in many forms. For some years it was disposed of principally to the railroads and burned as fuel on locomotives, and thus caused considerable industrial development in Texas, because it was necessary to sell the petroleum at prices as low as 10 cents per barrel in order to find a market for the product. After persistent endeavor it has become possible to refine this petroleum successfully, and some of the products have peculiar value. The lubricating oils find considerable favor and the gasoline has special value as a solvent.

California.—Petroleum, principally asphaltic and similar to the Texas petroleum, except that it is sometimes free from sulphur, is found in many areas in California, between Los Angeles and San Francisco, the principal fields being Los Angeles City, Puente Hills, Kern River, Sunset, McKittrick, Santa Maria, Coalinga, and Fullerton. The lack of an adequate supply of fuel in California has led to very great development of the petroleum industry for this purpose, as shown in the production tables below, and investigations have shown that the quantity of petroleum existing in California is greater than in any other known field in the United States.

Smaller fields.—The great fields described above are those which control the industry. West of the Mid-Continent field and east of the California field are several smaller ones (as thus far developed) in Colorado and Wyoming, with promises of fields in New Mexico, Utah, Idaho, Montana, Oregon, and Washington. In Alaska at least two petroleum pools have been discovered which may possibly be capable of considerable output when the market conditions become favorable.

There are many regions in the United States where there is no geological improbability of finding petroleum. Such geological improbability exists where the rocks are greatly disturbed and broken up to such a depth as to prevent probable drilling to the undisturbed sedimentary rocks which could furnish good storage for petroleum.

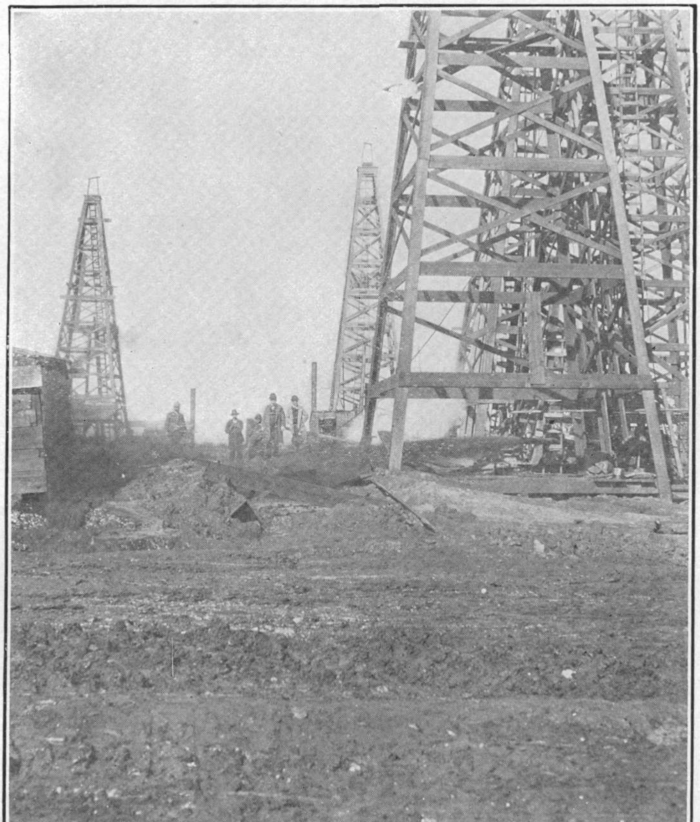


ILLUSTRATION OF THE CROWDING OF OIL WELLS, SPINDLETOP FIELD, TEXAS.

(Photograph by C. W. Hayes.)

AREAS.

In each petroleum field it has become necessary for the pipe-line companies and for the producers themselves to locate on detailed maps every well as it is drilled, distinguishing the productive from dry wells, in order that the limitations of each field may be promptly determined. From these maps, principally, with the aid of many independent data collected by himself, Dr. F. H. Oliphant has compiled a map of the petroleum fields in the United States, which is appended to this report. The following table, giving in square miles the area of petroleum territory in each State, has been compiled from measurements of the areas on this map, revisions being made from the map recently published by Dr. I. C. White, state geologist of West Virginia, and from data supplied by Dr. H. Foster Bain, director of the Geological Survey of Illinois; Ralph Arnold, in charge of the petroleum investigations in California for the United States Geological Survey; A. C. Veatch, for Wyoming; Dr. J. A. Bownocker, state geologist of Ohio; and by Doctor Oliphant himself. The figures here given are merely general approximations, which lack very much in uniformity. In some States the area shows simply actual "proved territory." In others, as in Alabama, it indicates the region in which the future production of petroleum is probable. In many others considerable territory is included between individual pools which in all probability will prove to be barren, and while the extensions of "proved territory" will, to a certain extent, offset that which proves eventually to be barren, the table is, at best, a rough approximation. It takes no account whatever of the fact that other fields now altogether unknown will be developed in the future.

State.	Square miles.	State.	Square miles.	State.	Square miles.
Alaska	100	Louisiana	60	Pennsylvania	2,000
Alabama	50	Michigan	80	Tennessee	80
California	850	Missouri	30	Texas	400
Colorado	200	New Mexico	80	Utah	40
Idaho	10	New York	300	West Virginia	570
Illinois	200	Ohio:		Wyoming	750
Indiana	1,000	Eastern	115		
Kansas	200	Western	535	Total	8,450
Kentucky	400	Oklahoma	400		

THICKNESS.

The thickness of the "pay sands" in these fields varies within wide limits. In West Virginia Doctor White considers 5 feet of "pay sand" to be a safe estimate in good producing territory. This is sufficiently liberal for Pennsylvania also. In other fields much thicker "pay sands" are recognized. In Illinois the "pay" streaks in the petroleum sands vary from 2 feet to over 30 feet in thickness, and at Spindle Top, in Texas, an average thickness of over 75 feet has been calculated. In California, particularly in the Kern River field, the "pay sands" reach a thickness of over 100 feet.

POROSITY.

The rocks composing the "pay" streaks in the petroleum-bearing formations of the United States vary from sandstones and dolomites, with the compactness of ordinary building stone, to unconsolidated sands and coarse gravel, and, in exceptional cases, honeycombed limestones, in which actual cavities of considerable size have to be reckoned with. It has been customary to consider 10 per cent as near the average porosity of the "pay sands," with a latitude of variation from practically nothing in damp shales to over 30 per cent in the most porous strata.

The principal effect of these variations in porosity is rather upon the rate at which the petroleum can be obtained from the pool than upon the total amount obtainable.

PROBABLE SUPPLY OF PETROLEUM.

CAPACITY OF SANDS.

Assuming 10 per cent as the average porosity of "pay sands," 1 cubic foot of "pay sand" would yield approximately 1 gallon of petroleum, or 5,000 barrels per acre of "pay sands" with an average thickness of 5 feet.

ESTIMATES OF YIELD.

The thickness most frequently reported for the "pay sands" of various fields is normally much in excess of 5 feet. In Pennsylvania, the reported thickness of petroleum-bearing strata will average more than this, and frequently more than one stratum has been noted in the same well, and yet, as will be shown in the tables of production below, the average yield per acre in Pennsylvania has been less than 800 barrels, and at the present rate of decline it is not probable that more than 800 barrels per acre will be obtained on the average in New York and Pennsylvania. It is fair to assume that 1,000 barrels per acre is a sufficient allowance for New York, Pennsylvania, West Virginia, Kentucky, Tennessee, Ohio, and Indiana. In Illinois, where the yields have been unusually great on account of "pay" streaks approximating 25 feet on the average, Doctor Bain estimates 8,000 barrels per acre as the result of conferences with the producers. This is taking into consideration the fact that in the northern portions of the field the yield is frequently not greater than 2,500 barrels per acre. In the Texas field the supply is better calculated by consideration of the amount already yielded and the rate of decline, from which it is estimated that the Texas fields will surely yield 200,000,000 barrels, and Louisiana 50,000,000 barrels. In Oklahoma the remaining productive capacity is estimated by Mr. W. J. Reed, of the United States Geological Survey, at a minimum of 282,875,000 barrels. In the remaining fields, outside of California, 1,000 barrels per acre is believed to be a sufficient allowance for the known fields.

In California very careful measurements by Mr. Arnold have resulted in an estimate of 8,500,000,000 barrels of petroleum stored in the rocks of that State, of which perhaps 5,000,000,000 barrels may be expected to be produced. Recognizing that the amount of oil obtainable from these known fields is a matter largely of conjecture, it can only be based as above, upon what the fields have already yielded, and upon the thickness and relative porosity of the sands, but estimates of different authorities must vary between wide limits, and this should be borne in mind in considering the following table.

Estimated minimum and maximum total yield of the petroleum fields of the United States.

	Minimum.	Maximum.
Appalachian field	2,000,000,000	5,000,000,000
Lima-Indiana field	1,000,000,000	3,000,000,000
Illinois field	350,000,000	1,000,000,000
Mid-Continent field	400,000,000	1,000,000,000
Gulf field	250,000,000	1,000,000,000
California field	5,000,000,000	8,500,000,000
Minor fields	1,000,000,000	5,000,000,000
Total	10,000,000,000	24,500,000,000

PRODUCTION OF PETROLEUM.

BEGINNING OF THE INDUSTRY.

Production of petroleum in the United States has been considered statistically only since 1859. The production to that date incidental to the salt industry, and the occasional use of petroleum from springs for medicinal purposes, had no bearing on the industry which was to follow, except in one way. Samuel Kier, of Pittsburg, had salt wells at Tarentum, from which he accumulated so much petroleum (more than 50 barrels) that he applied himself to the problem of developing a definite trade for it, and succeeded by means of introducing a lamp with a chimney. He also partly-refined this petroleum. A. C. Ferris, also of Pittsburg, applying himself in the same direction, began the distribution of this oil to other cities, and the efforts of these two merchants created and maintained a demand which caused Colonel Drake to drill a well for petroleum at Titusville in 1859. In the course of the half century since the drilling of the Drake well 1,806,608,463 barrels of petroleum, or 240,919,676 tons, have been produced, worth $1,654,877,685. Details of this production are shown in the following table:

Production of crude petroleum in the United States, 1859–1907, by years and by States, in barrels of 42 gallons.

Year.	Pennsylvania and New York.	Ohio.	West Virginia.	California.	Kentucky and Tennessee.	Colorado.	Indiana.	Illinois.
1859	2,000	....	....	....	....	....	....	....
1860	500,000	....	....	....	....	....	....	....
1861	2,113,609	....	....	....	....	....	....	....
1862	3,056,690	....	....	....	....	....	....	....
1863	2,611,809	....	....	....	....	....	....	....
1864	2,116,109	....	....	....	....	....	....	....
1865	2,497,700	....	....	....	....	....	....	....
1866	3,597,700	....	....	....	....	....	....	....
1867	3,347,300	....	....	....	....	....	....	....
1868	3,646,117	....	....	....	....	....	....	....
1869	4,215,000	....	....	....	....	....	....	....
1870	5,260,745	....	....	....	....	....	....	....
1871	5,205,234	....	....	....	....	....	....	....
1872	6,293,194	....	....	....	....	....	....	....
1873	9,893,786	....	....	....	....	....	....	....
1874	10,926,945	....	....	....	....	....	....	....
1875	8,787,514	....	....	....	....	....	....	....
1876	8,968,906	31,763	120,000	12,000	....	....	....	....
1877	13,135,475	29,888	172,000	13,000	....	....	....	....
1878	15,163,462	38,179	180,000	15,227	....	....	....	....
1879	19,685,176	29,112	180,000	19,858	....	....	....	....
1880	26,027,631	38,940	179,000	40,552	....	....	....	....
1881	27,376,509	33,867	151,000	99,862	....	....	....	....
1882	30,053,500	39,761	128,000	128,636	....	....	....	....
1883	23,128,389	47,632	126,000	142,857	4,755	....	....	....
1884	23,772,209	90,081	90,000	262,000	4,148	....	....	....
1885	20,776,041	661,580	91,000	325,000	5,164	....	....	....
1886	25,798,000	1,782,970	102,000	377,145	4,726	....	....	....
1887	22,356,193	5,022,632	145,000	678,572	4,791	76,295	....	....
1888	16,488,668	10,010,868	119,448	690,333	5,096	297,612	....	....
1889	21,487,435	12,471,466	544,113	303,220	5,400	316,476	33,375	1,460
1890	28,458,208	16,124,656	492,578	307,360	6,000	368,842	63,496	900
1891	33,009,236	17,740,301	2,406,218	323,600	9,000	665,482	136,634	675
1892	28,422,377	16,362,921	3,810,086	385,049	6,500	824,000	698,068	521
1893	20,314,513	16,249,769	8,445,412	470,179	3,000	594,390	2,335,293	400
1894	19,019,990	16,792,154	8,577,624	705,969	1,500	515,746	3,688,666	300
1895	19,144,390	19,545,233	8,120,125	1,208,482	1,500	438,232	4,386,132	200
1896	20,584,421	23,941,169	10,019,770	1,252,777	1,680	361,450	4,680,732	250
1897	19,262,066	21,560,515	13,090,045	1,903,411	322	384,934	4,122,356	500
1898	15,948,464	18,738,708	13,615,101	2,257,207	5,568	444,383	3,730,907	360
1899	14,374,512	21,142,108	13,910,630	2,642,095	18,280	390,278	3,848,182	360
1900	14,559,127	22,362,730	16,195,675	4,324,484	62,259	317,385	4,874,392	200
1901	13,831,996	21,648,083	14,177,126	8,786,330	137,259	460,520	5,757,086	250
1902	13,183,610	21,014,231	13,513,345	13,984,268	185,331	396,901	7,480,896	200
1903	12,518,134	20,480,286	12,899,395	24,382,472	554,286	483,925	9,186,411	....
1904	12,239,026	18,876,631	12,644,686	29,649,434	998,284	501,763	11,339,124	....
1905	11,554,777	16,346,660	11,578,110	33,427,473	1,217,337	376,238	10,964,247	181,084
1906	11,500,410	14,787,763	10,120,935	33,098,598	1,213,548	327,582	7,673,477	4,397,050
1907	11,211,606	12,207,448	9,095,296	39,748,375	820,844	331,851	5,128,037	24,281,973
Total	687,425,409	366,250,105	185,039,718	201,965,825	5,276,578	8,874,285	90,127,511	28,866,683

Production of crude petroleum in the United States, 1859–1907, by years and by States, in barrels of 42 gallons—Continued.

Year.	Kansas.	Texas.	Missouri.	Oklahoma.	Wyoming.	Louisiana.	United States.	Total value.
1859							2,000	$32,000
1860							500,000	4,800,000
1861							2,113,609	1,035,668
1862							3,056,690	3,209,525
1863							2,611,309	8,225,663
1864							2,116,109	20,896,576
1865							2,497,700	16,459,853
1866							3,597,700	13,455,398
1867							3,347,300	8,066,993
1868							3,646,117	13,217,174
1869							4,215,000	23,730,450
1870							5,260,745	20,503,754
1871							5,205,234	22,591,180
1872							6,293,194	21,440,503
1873							9,893,786	18,100,464
1874							10,926,945	12,647,527
1875							8,787,514	7,368,133
1876							9,132,669	22,982,822
1877							13,350,363	31,788,566
1878							15,396,868	18,044,520
1879							19,914,146	17,210,708
1880							26,286,123	24,600,638
1881							27,661,238	23,512,051
1882							30,349,897	23,631,165
1883							23,449,633	25,740,252
1884							24,218,438	20,476,924
1885							21,858,785	19,193,694
1886							28,064,841	20,028,457
1887							28,283,483	18,856,606
1888							27,612,025	17,950,353
1889	500	48	20				35,163,513	26,963,340
1890	1,200	54	278				45,823,572	35,365,105
1891	1,400	54	25	30			54,292,655	30,526,553
1892	5,000	45	10	80			50,514,657	25,906,463
1893	18,000	50	50	10			48,431,066	28,932,326
1894	40,000	60	8	130	2,369		49,344,516	35,522,095
1895	44,430	50	10	37	3,455		52,892,276	57,691,279
1896	113,571	1,450	43	170	2,878		60,960,361	58,518,709
1897	81,098	65,975	19	625	3,650		60,475,516	40,929,611
1898	71,980	546,070	10		5,475		55,364,233	44,193,359
1899	69,700	669,013	132		5,560		57,070,850	64,603,904
1900	74,714	836,039	[a] 1,602	6,472	5,450		63,620,529	75,752,691
1901	179,151	4,393,658	[b] 2,335	10,000	5,400		69,389,194	66,417,335
1902	331,749	18,083,658	[a] 757	37,100	6,253	548,617	88,766,916	71,178,910
1903	932,214	17,955,572	[a] 3,000	138,911	8,960	917,771	100,461,337	94,694,050
1904	4,250,779	22,241,413	[a] 2,572	1,366,748	11,542	2,958,958	117,080,960	101,175,455
1905	[c] 12,013,495	28,136,189	[a] 3,100	([d])	8,454	8,910,416	134,717,580	84,157,399
1906	[c] 21,718,648	12,567,897	[a] 3,500	([d])	[e] 7,000	9,077,528	126,493,936	92,444,735
1907	[c] 45,933,649	12,322,696	[a] 4,000	([d])	9,339	5,000,221	166,095,335	120,106,749
Total	85,881,278	117,819,991	21,471	1,560,313	85,785	27,413,511	1,806,608,463	1,654,877,685

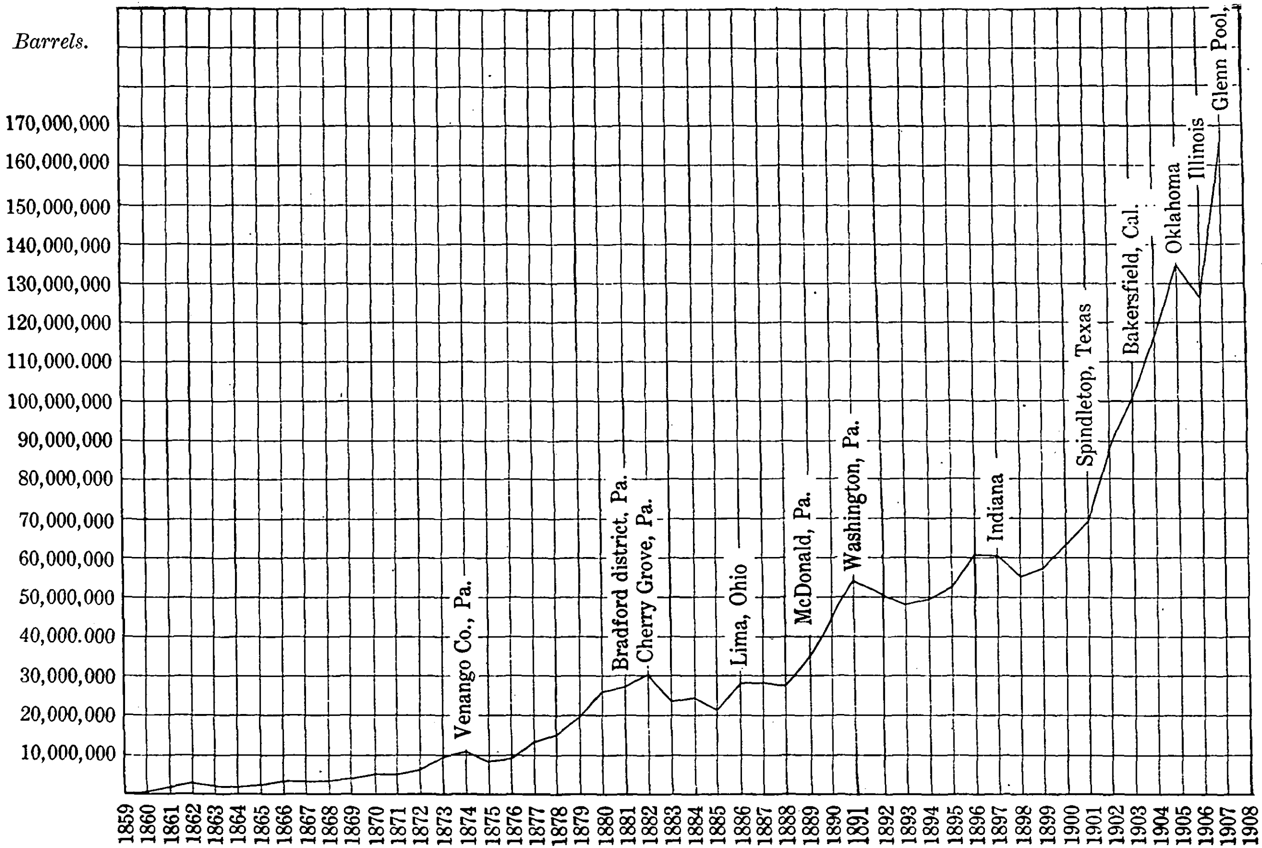
[a] Includes the production of Michigan.
[b] Includes production of Michigan and small production in Oklahoma.
[c] Includes production of Oklahoma.
[d] Included with Kansas.
[e] Estimated.

New petroleum fields have been found and developed so rapidly as to more than offset the decrease of production in the older fields. Therefore, the rate of total production has shown a rapid increase from 500,000 barrels in 1860 to over 166,000,000 barrels in 1907. The rate of production is illustrated by the curve (Pl. IV), on which are noted the sudden impulses resulting from the discovery of new fields. Grouped by the principal fields, the production of petroleum in the United States has been as follows:

Production of petroleum fields in each year from 1859 to 1907.

[Barrels of 42 gallons.]

Year.	Appalachian.	California.	Lima-Indiana.	Colorado-Wyoming.	Mid-Continent.	Gulf.	Illinois.	Total.
1859	2,000							2,000
1860	500,000							500,000
1861	2,113,609							2,113,609
1862	3,056,690							3,056,690
1863	2,611,309							2,611,309
1864	2,116,109							2,116,109
1865	2,497,700							2,497,700
1866	3,597,700							3,597,700
1867	3,347,300							3,347,300
1868	3,646,117							3,646,117
1869	4,215,000							4,215,000
1870	5,260,745							5,260,745
1871	5,205,234							5,205,234
1872	6,293,194							6,293,194
1873	9,893,786							9,893,786
1874	10,926,945							10,926,945
1875	8,787,514	3,000						8,790,514
1876	9,120,669	12,000						9,132,669
1877	13,337,363	13,000						13,350,363
1878	15,381,641	15,227						15,396,868
1879	19,894,288	13,543						19,907,831
1880	26,245,571	40,552						26,286,123
1881	27,561,376	99,862						27,661,238
1882	30,221,261	128,636						30,349,897
1883	23,306,776	142,857						23,449,633
1884	23,956,438	262,000						24,218,438
1885	21,533,785	325,000	36,178					21,894,963
1886	26,549,827	377,145	1,064,025					27,990,997
1887	22,878,241	678,572	4,650,375	76,295				28,283,483
1888	16,941,397	690,333	9,682,683	297,612				27,612,025
1889	22,355,225	303,220	12,186,564	316,476	500	48	1,460	35,163,493



ANNUAL PRODUCTION OF PETROLEUM, 1859 TO 1907.

1890	30,073,307	307,360	15,078,378	368,842	1,200	54	900	45,830,041
1891	35,848,777	323,600	17,452,612	665,480	1,430	54	675	54,292,628
1892	33,432,377	385,049	15,867,675	824,000	5,080	45	521	50,514,747
1893	31,365,890	470,179	15,982,097	594,390	18,010	50	400	48,431,016
1894	30,783,424	705,969	17,296,510	518,115	40,130	60	300	49,344,508
1895	30,960,639	1,208,482	20,236,741	441,687	44,467	50	200	52,892,266
1896	33,971,902	1,252,777	25,255,870	364,328	115,141	1,450	250	60,961,718
1897	35,230,271	1,903,411	22,805,033	388,584	147,648	65,975	500	60,541,422
1898	31,717,425	2,257,207	20,321,323	450,855	616,600	546,070	360	55,909,843
1899	33,068,356	2,642,095	20,225,356	395,838	738,183	669,013	360	57,739,201
1900	36,295,433	4,324,484	21,759,290	322,835	917,225	836,039	200	64,455,506
1901	33,618,171	8,786,330	21,933,379	465,920	989,696	4,393,658	250	70,187,404
1902	32,018,787	13,984,268	23,358,626	403,154	986,720	18,632,275	200	89,384,030
1903	31,558,248	24,382,472	24,080,264	492,885	1,573,085	18,873,343	....	100,960,297
1904	31,408,567	29,649,434	24,689,184	513,305	6,186,629	25,200,371	3,500	117,650,990
1905	29,366,960	33,427,473	22,294,171	384,692	12,533,777	37,046,605	181,084	135,234,762
1906	27,741,472	33,098,598	17,554,661	334,582	22,836,553	21,645,425	4,397,050	127,608,341
1907	25,342,137	39,748,375	13,121,094	341,190	46,846,267	16,636,610	24,281,973	166,317,646
Total	947,156,953	201,962,510	386,932,089	8,961,068	94,598,341	144,547,195	28,870,183	a 1,813,028,339

a Michigan and Missouri not included.

WELL RECORDS.

The production recorded above has resulted from the drilling of 287,922 wells, of which 232,982 were productive and 54,940 were dry holes. A distribution of these wells by fields is shown in the following table:

Wells drilled in petroleum fields in each year from 1859 to 1907.

Year.	Appalachian.		California.		Lima-Indiana.		Colorado-Wyoming.		Mid-Continent.		Gulf.		Illinois.		Total.	
	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.	Completed.	Dry.
1859	2	1													2	1
1860	49	39													49	39
1861	78	61													78	61
1862	92	72													92	72
1863	137	108													137	108
1864	226	180													226	180
1865	474	375													474	375
1866	442	350													442	350
1867	618	570													618	570
1868	928	208													928	208
1869	1,500	a 700													1,500	700
1870	1,664	a 800													1,664	800
1871	1,470	a 900													1,470	900
1872	1,183	a 400													1,183	400
1873	1,263	a 300													1,263	300
1874	1,317	a 200													1,317	200
1875	2,398	a 360	2												2,400	360
1876	2,920	438													2,920	438
1877	3,939	658	1												3,940	658
1878	3,064	328													3,064	328
1879	3,048	148	1												3,049	148
1880	4,217	144	3												4,220	144
1881	3,880	182	3												3,883	182
1882	3,304	179	3												3,307	179
1883	2,847	261	3												2,850	261
1884	2,265	270	4												2,269	270
1885	2,761	359	3		a 50	a 5									2,814	364
1886	3,478	525	5		a 100	a 10									3,583	535
1887	1,660	422	15		a 300	a 30	6								1,981	452
1888	1,505	371	45	30	531	27	46	24							2,127	452
1889	5,768	949	a 10	4	704	4	14	8	4		2		5		6,507	965

1890	6,358	1,049	*a* 10	5	1,969	193	2	....	8	2	....	....	....	....	8,347	1,249
1891	3,388	664	*a* 40	*a* 15	1,639	265	2	....	32	18	....	....	....	....	5,101	962
1892	1,968	462	*a* 60	*a* 20	1,741	259	2	....	....	....	....	....	....	....	3,771	741
1893	1,980	443	*a* 75	*a* 25	2,111	314	4	....	....	....	....	....	....	....	4,170	782
1894	3,763	875	*a* 75	*a* 20	3,661	565	2	....	50	16	....	....	....	....	7,551	1,476
1895	7,136	1,588	*a* 100	*a* 25	5,756	730	2	....	75	6	....	....	....	....	13,069	2,349
1896	7,824	1,901	*a* 175	*a* 30	5,638	708	34	18	137	78	....	....	....	....	13,808	2,735
1897	6,072	1,580	*a* 200	*a* 40	3,172	514	43	25	*a* 10	5	41	6	....	....	9,538	2,170
1898	4,792	1,269	*a* 275	*a* 50	3,088	384	103	30	*a* 12	*a* 4	374	32	....	....	8,644	1,769
1899	8,752	1,920	*a* 300	*a* 60	4,616	498	33	4	*a* 15	*a* 5	268	90	....	....	13,984	2,577
1900	8,845	2,160	*a* 500	*a* 100	5,738	662	31	13	*a* 30	*a* 10	373	98	....	....	15,517	3,043
1901	7,709	2,118	1,116	209	4,911	590	35	16	*a* 50	*a* 20	551	130	....	....	14,372	3,083
1902	7,722	2,131	422	102	6,460	725	10	....	293	37	*a* 500	*a* 100	....	....	15,407	3,095
1903	8,474	2,214	398	75	7,758	675	20	8	1,290	264	*a* 425	*a* 105	....	....	18,365	3,341
1904	8,859	2,383	458	158	6,897	623	25	10	3,557	475	463	186	2	....	20,261	3,835
1905	7,450	2,251	252	8	3,500	395	*a* 25	*a* 10	4,043	546	861	287	600	32	16,731	3,529
1906	7,568	1,934	174	7	2,743	304	*a* 30	*a* 12	3,876	501	1,081	352	3,585	500	19,057	3,610
1907	7,205	1,923	309	11	1,564	252	*a* 35	*a* 12	4,720	392	1,051	276	4,988	728	19,872	3,594
Total	174,362	39,723	5,037	994	74,647	8,732	504	190	18,202	2,379	5,990	1,662	9,180	1,260	287,922	54,940

a Estimated.

Total number of wells in operation in petroleum fields in each year from 1859 to 1907.

Year.	Appalachian.	California.	Lima-Indiana.	Colorado-Wyoming.	Mid-Continent.	Gulf.	Illinois.	Total.
1859	1							1
1860	11							11
1861	28							28
1862	48							48
1863	77							77
1864	123							123
1865	222							222
1866	313							313
1867	351							351
1868	1,058							1,058
1869	1,838							1,838
1870	2,673							2,673
1871	3,197							3,197
1872	3,481							3,481
1873	4,752							4,752
1874	5,821							5,821
1875	7,135	2						7,137
1876	8,817	2						8,819
1877	11,234	3						11,237
1878	13,400	3						13,403
1879	15,517	4						15,521
1880	18,627	7						18,634
1881	21,158	10						21,168
1882	22,245	13						22,258
1883	22,349	16						22,365
1884	21,063	20						21,083
1885	20,729	23	[a] 45					20,797
1886	20,782	26	[a] 135					20,943
1887	17,947	37	[a] 405	6				18,395
1888	15,433	48	909	28				16,418
1889	17,127	51	1,609	34	4	2	5	18,832
1890	19,850	[a] 53	3,385	36	10	2	5	23,341
1891	20,579	[a] 74	4,759	38	24	2	5	25,481
1892	19,683	[a] 111	6,196	40	24	2	5	26,061
1893	18,267	[a] 156	7,903	44	24	2	5	26,401
1894	19,717	[a] 191	10,829	40	58	2	4	30,841
1895	24,131	[a] 251	15,251	18	127	2	4	39,784
1896	25,235	[a] 390	19,481	30	176	2	4	45,318
1897	24,418	[a] 545	20,363	46	167	37	4	45,580
1898	25,217	[a] 745	21,693	117	175	377	4	48,328
1899	30,543	[a] 945	24,329	144	185	555	4	56,705
1900	35,691	[a] 1,295	27,608	158	171	830	4	65,757
1901	38,594	2,152	28,833	175	132	1,216	4	71,106
1902	38,637	2,397	29,542	183	329	[a] 1,274	4	72,366
1903	38,974	2,575	31,695	179	1,350	[a] 1,416		76,189
1904	40,958	2,715	30,235	176	4,424	1,418	2	79,928
1905	42,634	[a] 2,734	26,315	[a] 118	7,911	1,571	570	81,853
1906	41,436	2,661	18,901	[a] 107	10,270	1,900	3,655	78,930
1907	40,033	2,559	13,130	[a] 112	14,568	2,355	7,913	80,670

[a] Estimated.

LIFE OF A WELL.

Varying with the compactness of the "pay sand" and with the pressure of the gas accompanying the petroleum, the productive life of wells varies between the extreme limits of a few months on the one hand to more than twenty years on the other. In many regions in Pennsylvania the hard and compact sandstones have resulted in wells of unusually long life, such wells having an initial production of 50 to 500 barrels in the first twenty-four hours and "settling down" to a comparatively steady production of perhaps one-tenth of that amount. This has continued for years with gradual decline, and after even twenty years many of such wells are still being pumped, with a production reduced to one-tenth of a barrel per day. The other extreme, of short-lived wells, is represented by the Spindle Top type, where, from very loose sands, wells have spouted many thousands of barrels in the first twenty-four hours, have shown a correspondingly rapid decline, and have become exhausted and been abandoned within six months to four years from the time when first drilled. The experience of petroleum producers in Pennsylvania has shown seven years to be a fair average life of a well.

Adopting this average for the Appalachian, Lima-Indiana, Illinois, and Mid-Continent fields, four years for Texas, six years for California, and seven years for the minor petroleum fields, tables have been computed showing the probable number of active wells which contributed to each year's production. This has been done by adding to the existing wells all the new productive wells drilled in each year and subtracting all wells when they reached the prescribed age limit. From these tables the average daily yield of the wells of each region has been estimated:

Average production per well per day in each field from 1859 to 1907.

[Barrels of 42 gallons.]

Year.	Appalachian.	California.	Lima-Indiana.	Colorado-Wyoming.	Mid-Continent.	Gulf.	Illinois.	Average.
1859	5.48							5.48
1860	124.19							124.19
1861	206.81							206.81
1862	174.47							174.47
1863	92.91							92.91
1864	47.01							47.01
1865	30.82							30.82
1866	31.49							31.49
1867	26.13							26.13
1868	9.44							9.44
1869	6.28							6.28
1870	5.39							5.39
1871	4.46							4.46
1872	4.94							4.94
1873	5.70							5.70
1874	5.14							5.14
1875	3.37	4.11						3.74
1876	2.83	16.39						9.61
1877	3.25	11.87						7.56
1878	3.14	13.91						8.53
1879	3.51	9.28						6.40
1880	3.86	15.83						9.85
1881	3.57	27.36						15.47
1882	3.72	27.11						15.42
1883	2.86	24.46						13.66
1884	3.11	35.74						19.43
1885	2.85	38.70	2.20					14.58
1886	3.50	39.74	21.59					21.61
1887	3.49	50.24	31.46	34.83				30.01
1888	3.00	39.30	29.10	29.04				25.11
1889	3.58	16.28	20.75	25.50	.35	.07	.80	9.62
1890	4.15	15.88	12.20	28.07	.34	.08	.50	8.75
1891	4.77	11.98	10.05	47.98	.16	.08	.36	10.77
1892	4.64	9.50	7.00	56.29	.24	.06	.28	11.14
1893	4.70	8.26	5.54	37.01	2.05	.07	.22	8.26
1894	4.23	10.12	4.38	35.49	1.89	.08	.20	8.06
1895	3.52	13.19	3.64	67.23	.96	.07	.13	12.68
1896	3.68	8.78	3.54	33.10	1.79	1.98	.18	7.58
1897	3.95	9.57	3.07	23.14	2.43	4.89	.35	6.77
1898	3.45	8.30	2.57	10.56	9.65	3.97	.25	5.54
1899	2.97	7.66	2.28	7.53	10.93	3.30	.25	4.99
1900	2.79	9.15	2.16	5.60	14.70	2.76	.13	5.33
1901	2.39	11.19	2.08	7.29	20.54	9.90	.18	7.65
1902	2.27	15.99	2.17	6.04	8.22	40.07	.13	10.70
1903	2.22	25.94	2.07	7.54	3.19	36.51		11.07
1904	2.10	29.84	2.23	7.97	3.82	48.56	4.80	14.19
1905	1.89	33.49	2.32	8.93	4.34	64.61	.87	16.64
1906	1.83	34.07	2.54	8.57	6.09	31.21	3.30	12.52
1907	1.73	42.56	2.74	8.35	8.81	19.35	8.37	13.13
Average	18.11	20.47	7.73	23.62	5.29	14.08	1.12	

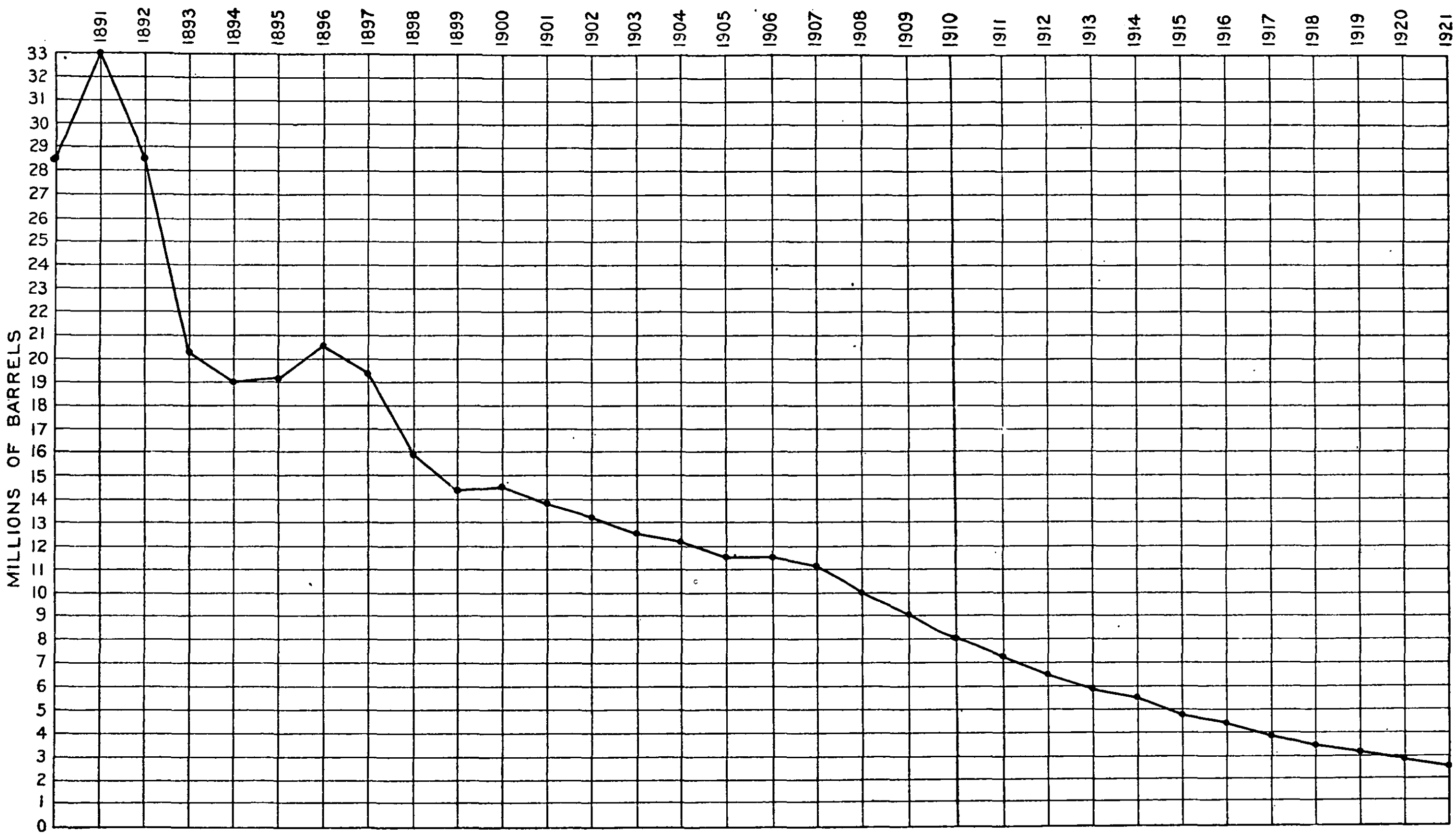
DURATION.

PRODUCTION CURVE.

The rate of petroleum production, graphically portrayed in the curve on Plate IV, shows that beginning with 1860 as much petroleum has been produced in each nine years as the entire product preceding this nine years. Continuing this rate of increase the next nine years would produce 1,800,000,000 barrels, making the total amount extracted up to 1916 3,600,000,000 barrels. In 1925 the amount extracted would reach 7,200,000,000, and in 1934 14,400,000,000 barrels, and nine years more, 1943, would bring the total to almost the maximum amount estimated as obtainable from the present fields. Concerning the probability of such a rate of increase in production, one must consider the causes for the great increase in past years. The vital factor has been the ease with which any quantity of oil could be sold for cash at any time and for prices ordinarily much above the cost of production. This ready market has not been seriously disturbed even by the greatly increased production of the past few years. The second reason is based upon the liquid character of the product. With the discovery of each new field the territory is divided into many leaseholdings, frequently small in size. In pumping from one lease petroleum is apt to flow in from a rival interest. It is therefore necessary for each lessee to "get his share" before it flows away to drained territory. It is impossible to prevent the consequent rapid depletion of a field without a combination of all the interests, or by limiting by statute the amount that each producer shall extract per acre within a specified time. General industrial conditions have had little effect in regulating the production of petroleum, as has been the case with coal. The purchaser for cash has always been on hand. Even if the price paid has been low, it has been above the cost of production. The surplus has been readily marketed abroad, or burned as a substitute for coal.

Oil's independence of industrial conditions is also shown by the inability of the production to respond to greatly increased trade demand. It requires the development of new territory to greatly increase the production. Otherwise the developed fields rapidly fall into the stage of decline, which is more or less rapid as the oil sands are loose or compact. Without the opening of new territory there is no probability of continuing the indicated rate of increase. The production of the present year could not be maintained beyond a very few years. The duration of the supply will thus be extended, but with a production inadequate to legitimate demands, as the production in the past has been excessive.

Under conditions of an insufficient supply, the relations of price to production must more closely follow supply and demand. the con-



DECLINE IN PRODUCTION OF THE NEW YORK AND PENNSYLVANIA OIL FIELDS AND ITS PROBABLE RATE IN THE FUTURE.

ditions governing which have been pointed out in connection with our better known supply of coal, but there must always remain the exceptional feature of rival producers vying in the extraction of petroleum from the same reservoir.

RAPIDLY DECLINING FIELDS.

The production tables show that in seventeen years Pennsylvania and New York have decreased to a third of their greatest output. The decline has become regular, and, logically extended, will render the production negligble in ten years (Pl.V). The production per well per day has fallen from a maximum average of 207 barrels to 1.7 barrels, showing that increasing the number of wells is not significantly effective in stimulating the product. In fact, many very old wells are contributing to the product with as little as one-tenth of a barrel per day.

The production in West Virginia has declined to 56 per cent of the maximum output, and new developments of great magnitude are not looked for. This State is also in the rapidly declining class.

The rate in Kentucky and Tennessee is not easily predicted, but there is no territory which has yet been proved to rank among the great producers. Ohio and Indiana are declining more rapidly at present than Pennsylvania. In Texas the decline is also rapid, and a total of only 200,000,000 barrels is estimated from the present pools. In Kansas the decline has been rapid and the production has now reached a small fraction of the previous yield and a stage where the future decline will be slower.

INCREASING TERRITORY.

Illinois and Oklahoma, in the Mid-Continent field, and California can be expected to show greater yields. In Illinois the limitations of the new fields have not been reached, and the possibilities of considerable extensions render an increase in the yield probable for several years. The same is true in Oklahoma, particularly in the so-called "shallow pool."

TIME OF EXHAUSTION.

Regarding the limits of time within which the present supply will be exhausted, it is clear that considering the minimum quantity of petroleum in the United States as 15,000,000,000 barrels, and continuing the present rate of increase in production, the supply would be exhausted about 1935. If the present annual production were continued without increase, 90 years would be required to exhaust this estimated minimum quantity. A reasonable view of the situation makes it probable that the present annual rate of production will be increased slightly through the developments of Illinois, Oklahoma, and California, but that within a very few years a marked decline will be noted, and this will continue with increasing value for the oil product and an insufficient quantity for the legitimate demands of the industry after another decade, and that the production, on a reduced scale, will continue for a long time, but in an amount unsatisfactory to industrial necessity, except as supplemented from new fields.

NATURE AND EXTENT OF WASTE IN THE EXTRACTION OF PETROLEUM.

STORAGE.

Waste, as understood in the natural-gas industry, has been markedly absent with petroleum. Very rarely has it proved impossible to furnish storage for some exceptionally prolific gusher. In 1907 lack of storage in the Mid-Continent field resulted in wasting a large amount of petroleum, estimated at 1 per cent of the total production, for which no storage was available. A similarly exceptional waste resulted in 1901 from the unexpected gushers in the Spindle Top pool in Texas.

LACK OF FORESIGHT ABROAD.

The record of the United States in providing sufficient storage in steel tanks is far better than that of the other petroleum fields of the world. In Russia lack of foresight in opening unusually strong gushers has not only led to repeated enormous waste of petroleum, but to fires which have involved the destruction of large cities. Nowhere else in the world have the emergencies of the petroleum production been met with the keen foresight and prompt treatment characteristic of the United States.

EVAPORATION.

Another form of waste of petroleum products of Europe and of the East, which has been avoided in the United States, is evaporation of gasoline and of similar light products when the petroleum is exposed to the air in open tanks. These light products form the most valuable portion of petroleum. A thin layer of any ordinary light crude petroleum will become heavy and valueless by exposure to the sun for a single day. This has been a source of great loss in the open earthen tanks which have been much used in Russia. In the United States, on the other hand, only under very exceptional circumstances has the earthen tank been used, and then only pending the completion of steel tankage. The rapidity with which great numbers of steel tanks, often holding as much as 55,000 barrels, have been constructed is a remarkable tribute to the engineering skill of the oil-transportation companies. It is due, also, to the conditions of the iron industry, which make it possible to furnish suitable steel promptly for such emergencies. On an average, one tank per day was completed in the Mid-Continent field in 1907.

WASTE IN THE USE OF PETROLEUM.

The principal waste in the petroleum industry is connected with its utilization. In the face of an approaching scarcity, the use of petroleum should be limited to the purposes for which it is essential and for which no other material can be substituted.

ESSENTIAL USES.

Petroleum may be regarded as indispensable for the lighting of isolated houses, and for every small establishment not in connection with a gas or electric supply. The prices at which lamp oils can be sold are lower than the prices of any substitute under isolated conditions. The economic necessity, therefore, of securing the greatest amount of illuminating oil from crude petroleum is evident.

ABSOLUTE NECESSITY OF OIL FOR LUBRICATION.

A still more essential use of petroleum is for lubricating all bearings in every kind of machinery. This is necessary in the development of power by any means. The following table gives some indication of the amount of lubricating oil consumed in various kinds of power production. At least one-half pint of lubricating oil is used for every ton of coal converted into power, and when this power is carried further to its ultimate uses, such as the moving of railroad cars, and when account is taken of the machinery depending on hand power, including sewing machines, clocks, watches, etc., this necessary oil is probably doubled in amount. The conservation, therefore, of a proportionate amount of lubricating oil, consistent with all industrial activity, must become a part of the general plan for civilized progress. It should be noted that from 10 to 15 per cent is as large an amount of lubricating oil as is now obtained from crude petroleum.

Average amount of lubricating oil required for power.

	Gallon of oil per ton of coal.	Gallon of oil per horse-power day.	
Street railway power station	0.168	0.0021	Including crank case, cylinder, and engine oil.
Niagara Falls power house	.024	.0003	Doubtless supplemented by water lubrication.
Fleet of 167 steam vessels, total indicated horsepower, 480,900.	.209	.0025	Machine and cylinder oil.
New England industrial plants:			
No. 1	.400	.0048	Cylinder oil.
No. 2	.200	.0024	
No. 3	.670	.0080	
No. 4	.500	.0060	
Average	.310	.0037	

UNNECESSARY USES.

In 1907 there were 18,855,691 barrels of crude petroleum burned as fuel in locomotives, and a large proportion of the California production was used for the development of power, principally by burning it for the generation of steam. Whenever a large increase is made in the production of petroleum with a corresponding decrease in price, the producers are grateful for any outlet for their oil and sell it for such low-grade uses, in which it brings not more than one hundredth part and has brought as low as one thousandth part of the maximum price for high-grade petroleum products. Much of this crude petroleum, had it remained stored in the ground, could later have been converted into far more valuable products. Much petroleum has been used for oiling roads. The skillful application of petroleum residues to poor road surfaces has proved so effective that this use is justifiable, but the use of crude petroleum for such purposes can seldom be considered in any other light than as a waste, especially as coal-tar residues and waste products of the coking and illuminating-gas industry serve this purpose well enough.

EXPORTS.

The greatest waste of petroleum has been in exporting crude petroleum and petroleum products to foreign countries. The necessity for it has been due to the sudden increase of production, due to the discovery and immediate development of the larger fields, and only by this means has it been possible for the producers to continue to obtain a constant market for petroleum, wherever produced. This immediate purchase of the product has meant a gain of millions of dollars to the producers.

METHODS OF PREVENTING OR LESSENING WASTE IN THE PETROLEUM INDUSTRY.

CHECKING UNNECESSARY PRODUCTION.

At present, more petroleum is being produced than is necessary for the legitimate demands of the industry. Within ten years the present fields will be unable profitably to produce enough for these legitimate requirements. Inasmuch as the lands now owned by private interests are leased by rival concerns, it is impossible to prevent each rival from producing petroleum as rapidly as he desires. The only direction in which production can be checked is with the petroleum contained in public lands. Offering such public land for entry at a nominal price is nothing more than temptation to the private citizen to waste petroleum by overproduction, since lands yielding hundreds of dollars per acre in this product can be obtained for a nominal sum. Every acre of public land believed to contain supplies of petroleum or natural gas should be withdrawn from every form of entry and should be subjected to an equitable system of lease. By this means undoubtedly a large amount of petroleum would be reserved for use when the supply becomes inadequate to industrial demands. It should be noted that since the advance copies of this report appeared in the public press, the petroleum producers of Oklahoma have arranged to reduce production in that State.

BETTER COMBUSTION.

The use of petroleum as a form of power is justified on the Pacific coast, provided attention is given to securing the maximum amount of power per unit of oil. This is not consistent with burning oil under stationary boilers for the production of steam, but prompt study should be given to the development of internal-combustion engines capable of using crude petroleum or, more particularly, less valuable residuum. It should be noted that private enterprise has already done much for the successful solution of this problem.

HOW SUPPLIES OF PETROLEUM MAY BE EXTENDED.

PREVENTION OF WASTE IN EXTRACTION AND IN USE.

Legislation tending to the capping of gas wells in petroleum fields, to preserve the pressure, and to prevent the unnecessary encroachment of water, should be extended to all States where petroleum is produced. After the practical exhaustion of the field by this encroachment of water, the remaining petroleum can frequently be washed into smaller but still profitable pools—a system which is already intelligently used in this country.

DISCOVERY AND DEVELOPMENT OF SUBSTITUTES.

Alcohol from grain, potatoes, and waste products can be used in the place of petroleum as an illuminant and for power in place of gasoline whenever the necessity arises. No practical substitute is known for mineral lubricating oils. Animal and vegetable oils are excluded as entirely too expensive. The production of artificial petroleum from various vegetable and animal waste products has received sufficient study to indicate the possibility of good results if scientific research is encouraged in this direction.

NECESSITY OF SCIENTIFIC RESEARCH.

The most practical recommendation seems to be the encouragement of scientific research in the study of the conditions of occurrence of petroleum in the earth, in order to lessen the expense of discovery of new pools. A second line of scientific research of even greater value should include fundamental studies of the nature of all kinds of petroleum, with a view to converting less valuable varieties into higher grades and to producing greater proportions of the absolutely necessary lubricating oils from crude petroleum. Such scientific study should be initiated at once to be of benefit when the present petroleum supply becomes inadequate.

RECOMMENDATIONS.

Three conclusions are self-evident from this report.

First. It is absolutely necessary for the preservation of an adequate supply of petroleum that all public lands where petroleum is probable should at once be withdrawn from entry.

Second. A general investigation of the conditions of accumulation of petroleum and its geographic distribution should be undertaken in order that the petroleum-bearing public lands may be selected.

Third. Fundamental scientific study of the nature of petroleum, especially with a view to securing the greatest yields of the most valuable constituents and even for transmuting one oil into another, is required for its most intelligent use.

NATURAL-GAS RESOURCES OF THE UNITED STATES.

By David T. Day.

THE GAS FIELDS.

DISTRIBUTION.

The conditions favorable to the accumulation of gas reservoirs are in general the same as for petroleum. The two usually overlap. More or less gas is always found dissolved in crude petroleum, and the amount of gas obtained at a given pressure from a sand of slight thickness leads to the belief that the gas is dissolved in the petroleum under pressure, in a manner similar to the solution of carbonic acid in water. Reservoirs filled with dry gas are often found—almost always in the neighborhood of petroleum fields—though beds of coal often yield natural gas, even when far from oil wells, as in the anthracite mines of Pennsylvania, where gas is found more than 100 miles distant from any petroleum pool.

AREAS.

The areas shown on the accompanying petroleum and gas map (Pl. II) comprise the regions in which either natural gas or petroleum is the more valuable product. The limits of these areas have been revised since the map was published, and they now show the following measurements in square miles:

State.	Square miles.	State.	Square miles.	State.	Square miles.
Alabama	40	Missouri	70	South Dakota	80
California	310	Montana	40	Texas	130
Colorado	80	New York	550	Utah	40
Illinois	50	Ohio:		Washington	70
Indiana	2,460	Eastern	110	West Virginia	1,000
Kansas	550	Western	165	Wyoming	120
Kentucky	290	Oklahoma	1,000		
Louisiana	110	Oregon	20	Total	10,055
Michigan	40	Pennsylvania	2,730		

PRESSURE.

Estimates of the total yield, in cubic feet, which can be expected from the gas pools are ordinarily obtained by measuring the pressure with a Pitot tube, calculating by a simple formula the cubic feet per day, and observing the rate of decline.

The closed or rock pressures in various fields, in so far as reliable records are available, are given in the following table for various years:

Pressure of natural gas in various fields at various dates.

[In pounds per square inch.]

	Illinois.	Indiana.	Kansas.	Kentucky.	New York.	Ohio.	Oklahoma.	Pennsylvania.	Texas.	West Virginia.
1885	400–450	....	....	....	....	450	....	150–575	....	....
1886	125	325–400	110	....	....	400	....	200–460	....	550–680
1887	....	320–340	....	....	....	[a] 750; [b] 650	....	200–380	....	....
1888	300	325	....	125	....	[b] 450	....			....
1889	....	325	....	....	400	250–390	....	....	....	....
1890	....	....	....	....	240	170–275	....	....	....	1,000
1893	....	280	....	....	....	....	....	....	....	....
1894	60	260	200	....	....	....	....	250	....	....
1895	40	240	....	[c] 60; [d] 250–300	....	[b] 50–150	....	150	....	....
1896	25	220	100	285–300	....	[a] 750; [b] 45	....	85	....	600–900
1897	....	195	250	....	1,500	[b] 30	....	....	....	100–1,100
1898	....	165	....	....	....	....	....	....	....	600–1,200
1899	[e] 3–30	150	300–325	....	200	....	....	....	....	1,200
1900	....	110	[f] 310–320; [g] 150	....	....	[a] 300–400; ([b] [h])	....	....	....	1,200
1901	....	80	....	....	....	....	....	....	[i] 250	1,000–1,300
1902	....	50	....	....	....	[a] 100; [j] 800	....	....	....	1 000–1,250
1903	....	....	....	....	....	....	....	400	....	850–1,250
1904	....	155; [k] 305–400	550–650	....	....	....	....	....	....	....
1906	150–435	22–156	90–282	....	45–335	121–352	217–468	41–486	....	144–516

[a] Lancaster.
[b] Northwestern Ohio.
[c] Western Kentucky.
[d] Eastern Kentucky.
[e] Bureau County.
[f] Allen County.
[g] Neosho County.
[h] Reduced to almost no pressure.
[i] Beaumont.
[j] Homer.
[k] Southern Indiana.

The paucity of actual data is evident from the table above. It is useful only in showing the generally rapid decline of the high pressures.

PRODUCTION.

The following tables show the value of the natural gas thus far produced. It has been possible only in the last two years to determine the quantity, in addition to the value of gas produced, but this shows that the quantity produced, as well as the price, is increasing.

Approximate value of natural gas produced in the United States, 1882–1907, by States.

State.	1882.	1883.	1884.	1885.	1886.	1887.
Pennsylvania	$75,000	$200,000	$1,100,000	$4,500,000	$9,000,000	$13,749,500
New York	....	....	....	196,000	210,000	333,000
Ohio	....	....	....	100,000	400,000	1,000,000
West Virginia	....	....	....	40,000	60,000	120,000
Illinois	....	....	....	1,200	4,000	....
Indiana	....	....	....	....	300,000	600,000
Kansas	....	....	....	....	6,000	....
Other	140,000	275,000	360,000	20,000	32,000	15,000
Total	215,000	475,000	1,460,000	4,857,200	10,012,000	15,817,500

Approximate value of natural gas produced in the United States, 1882–1907, by States—Continued.

State.	1888.	1889.	1890.	1891.	1892.	1893.
Pennsylvania	$19,282,375	$11,593,989	$9,551,025	$7,834,016	$7,376,281	$6,488,000
New York	332,500	530,026	552,000	280,000	216,000	210,000
Ohio	1,500,000	5,215,669	4,684,300	3,076,325	2,136,000	1,510,000
West Virginia	120,000	12,000	5,400	35,000	70,500	123,000
Illinois	....	10,615	6,000	6,000	12,988	14,000
Indiana	1,320,000	2,075,702	2,302,500	3,942,500	4,716,000	5,718,000
Kansas	....	15,873	12,000	5,500	40,795	50,000
Missouri	....	35,687	10,500	1,500	3,775	2,100
California	....	12,680	33,000	30,000	55,000	62,000
Kentucky and Tennessee	....	2,580	30,000	38,993	43,175	68,500
Texas and Alabama	....	1,728	....	....	100	50
Arkansas and Wyoming	....	375	....	250	100	100
Utah	....	....	....	....	....	500
Other	75,000	1,600,175	1,606,000	250,000	200,000	100,000
Total	22,629,875	21,107,099	18,792,725	15,500,084	14,870,714	14,346,250

State.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
Pennsylvania	$6,279,000	$5,852,000	$5,528,610	$6,242,543	$6,806,742	$8,337,210	$10,215,412
New York	249,000	241,530	256,000	200,076	229,078	294,593	335,367
Ohio	1,276,100	1,255,700	1,172,400	1,171,777	1,488,308	1,866,271	2,178,234
West Virginia	395,000	100,000	640,000	912,528	1,334,023	2,335,864	2,959,032
Illinois	15,000	7,500	6,375	5,000	2,498	2,067	1,700
Indiana	5,437,000	5,203,200	5,043,635	5,009,208	5,060,969	6,680,370	7,254,539
Kansas	86,600	112,400	124,750	105,700	174,640	332,592	356,900
Missouri	4,500	3,500	1,500	500	145	290	547
California	60,350	55,000	55,682	50,000	65,337	86,891	79,083
Kentucky and Tennessee	89,200	98,700	99,000	90,000	103,133	125,745	....
Alabama Texas	50	20	....	....	765	8,000	 20,000
Arkansas and Wyoming	100	100	60	40	....	....	....
Utah	500	20,000	20,000	15,050	7,875	....	....
Kentucky	....	....	....	....	....	....	286,243
Colorado	12,000	7,000	4,500	4,000	3,300	1,480	1,800
South Dakota	....	....	....	....	....	3,500	9,817
Other	50,000	50,000	50,000	20,000	20,000	....	....
Total	13,954,400	13,006,650	13,002,512	13,826,422	15,296,813	20,074,873	23,698,674

State.	1901.	1902.	1903.	1904.	1905.	1906.	1907.
Pennsylvania	$12,688,161	$14,352,183	$16,182,834	$18,139,914	$19,197,336	$18,558,245	$18,844,156
New York	293,232	346,471	493,686	522,575	623,251	672,795	766,157
Ohio	2,147,215	2,355,458	4,479,040	5,315,564	5,721,462	7,145,809	8,718,562
West Virginia	3,954,472	5,390,181	6,882,359	8,114,249	10,075,804	13,735,343	16,670,962
Illinois	1,825	1,844	3,310	4,745	7,223	87,211	143,577
Indiana	6,954,566	7,081,344	6,098,364	4,342,409	3,094,134	1,750,715	1,572,605
Kansas	659,173	824,431	1,123,849	1,517,643	2,261,836	4,010,986	4,843,019
Missouri	1,328	2,154	7,070	6,285	7,390	7,210	17,010
California	67,602	120,648	104,521	114,195	133,696	134,560	168,397
Alabama	....	....	....				
Texas	18,577	14,953	13,851	14,082	14,409	150,695	178,276
Louisiana	....	....	....	....	1,500		
Kentucky	270,871	365,356	390,301	322,104	237,290	287,501	380,176
Tennessee	....	300	300	300	300	300	300
Arkansas and Wyoming	....	....	2,460	6,515	21,135	34,500	126,582
Colorado	1,800	1,900	14,140	14,300	20,752	22,800	
South Dakota	7,255	10,280	10,775	12,215	15,200	15,400	19,500
Oklahoma	....	360	1,000	49,665	130,137	259,862	417,221
North Dakota	....	....	....	....	....	....	235
Oregon	....	....	....	....	....	....	100
Total	27,066,077	30,867,863	35,807,860	38,496,760	41,562,855	46,873,932	52,866,835

Value of natural gas consumed in the United States, 1902–1907, by States.

State.	1902.	1903.	1904.	1905.	1906.	1907.
Pennsylvania	$13,942,783	$16,060,196	$17,205,804	$19,237,218	$21,085,077	$22,917,547
Ohio	4,785,766	7,200,867	9,393,843	10,396,633	12,652,520	15,227,780
Kansas	824,431	1,123,849	1,517,643	2,265,945	} 4,030,776	4,853,298
Missouri	2,154	7,070	6,285	7,390		17,010
West Virginia	2,473,174	3,125,061	3,383,515	3,586,608	3,720,440	3,757,977
New York	1,723,709	1,944,667	2,222,980	2,434,894	2,654,115	3,098,533
Indiana	a 6,710,080	a 5,915,367	a 4,282,409	a 3,056,634	a 1,750,755	1,570,605
Kentucky	255,481	280,426	268,264	237,290	287,501	380,176
Oklahoma	360	1,000	49,665	126,028	247,282	406,942
Alabama	....	....	} 14,082	} 14,409	} 150,695	178,276
Texas	14,953	13,851				
Louisiana	....	....	....	1,500		
California	120,648	104,521	114,195	133,696	134,560	168,397
Illinois	1,844	3,310	4,745	7,223	87,211	143,577
Arkansas	....	} 2,460	6,515	21,135	34,500	} 126,582
Wyoming	....					
Colorado	1,900	14,140	14,300	20,752	22,800	
South Dakota	10,280	10,775	12,215	15,200	15,400	19,500
Tennessee	300	300	300	300	300	300
North Dakota	....	....	....	....	....	235
Oregon	....	....	....	....	....	100
Total	30,867,863	35,807,860	38,496,760	41,562,855	46,873,932	52,866,835

a A portion of this was consumed in Chicago, Ill.

Distribution of natural gas consumed in the United States in 1906, by States.

State.	Number of producers.	Consumers.		Gas consumed.		
				Domestic.		
		Domestic.	Industrial.	Quantity, M cubic feet.	Cents per M cu. ft.	Value.
Pennsylvania	309	273,184	3,307	41,135,808	22.2	$9,128,837
Ohio	409	310,175	3,316	33,049,479	24.7	8,165,567
Kansas	130	} 79,512	995	9,576,572	17.5	1,673,979
Missouri	19					
West Virginia	67	51,281	913	9,619,147	15.5	1,489,473
New York	143	74,538	95	8,999,871	27.7	2,495,040
Indiana	578	47,368	156	5,049,759	27.8	1,403,987
Kentucky	45	17,216	18	679,941	40.5	275,860
Oklahoma	50	8,391	202	1,446,879	11.8	170,774
Alabama	2	1	1	} 273,919	30.4	83,320
Louisiana	4	2,700	28			
Texas	5	702	1			
California	18	5,537	10	122,577	97.3	119,338
Illinois	66	1,429	2	359,556	22.8	82,211
Arkansas	4	1,700	4	} 58,500	49.1	28,711
Wyoming	3	3	4			
Colorado	3	800	11	20,500	100.0	20,500
South Dakota	13	406	10	12,900	88.4	11,400
Tennessee	3	1	1	400	25.0	100
Total	1,871	874,944	9,074	110,405,808	22.7	25,149,097

Distribution of natural gas consumed in the United States in 1906, by States—Continued.

State.	Gas consumed.					
	Industrial.			Total.		
	Quantity, M cubic feet.	Cents per M cu. ft.	Value.	Quantity, M cubic feet.	Cents per M cu. ft.	Value.
Pennsylvania	120,959,365	9.9	$11,956,240	162,095,173	13.0	$21,085,077
Ohio	41,763,083	10.7	4,486,953	74,812,562	16.9	12,652,520
Kansas, Missouri	59,891,889	3.9	2,356,797	69,468,461	5.8	4,030,776
West Virginia	48,835,862	4.6	2,230,967	58,455,009	6.3	3,720,440
New York	1,182,551	13.4	159,075	10,182,422	26.0	2,654,115
Indiana	2,811,781	12.3	346,768	7,861,540	22.2	1,750,755
Kentucky	109,213	10.6	11,641	789,154	36.4	287,501
Oklahoma	1,961,249	3.9	76,508	3,408,128	7.2	247,282
Alabama, Louisiana, Texas	764,650	8.8	67,375	1,038,569	14.5	150,695
California	30,444	50.0	15,222	153,021	87.9	134,560
Illinois	50,000	10.0	5,000	409,556	21.3	87,211
Arkansas, Wyoming	62,000	9.3	5,789	120,500	28.6	34,500
Colorado	3,067	75.0	2,300	23,567	96.7	22,800
South Dakota	10,000	40.0	4,000	22,900	67.2	15,400
Tennessee	1,600	12.5	200	2,000	15.0	300
Total	278,436,754	7.8	21,724,835	388,842,562	12.1	46,873,932

Quantity and value of natural gas produced and consumed in the United States in 1906, by States.

State.	Produced.			Consumed.		
	Quantity, M cubic feet.	Cts. per M cu. ft.	Value.	Quantity, M cubic feet.	Cts. per M cu. ft.	Value.
Pennsylvania	138,161,385	13.4	$18,558,245	162,095,173	13.0	$21,085,077
Ohio	45,436,020	15.7	7,145,809	74,812,562	16.9	12,652,520
West Virginia	119,400,392	11.5	13,735,343	58,455,009	6.3	3,720,440
Kansas	69,322,633	5.8	4,010,986	69,468,461 (Kansas and Missouri)	5.8	4,030,776
Missouri	33,560	21.5	7,210			
New York	2,547,769	26.4	672,795	10,182,422	26.0	2,654,115
Indiana	7,861,140	22.2	1,750,715	7,861,540	22.2	1,750,755
Kentucky	789,154	36.4	287,501	789,154	36.4	287,501
Oklahoma	3,520,396	7.3	259,862	3,408,128	7.2	247,282
California	153,021	87.9	134,560	153,021	87.9	134,560
Alabama, Louisiana, Texas	1,038,569	14.5	150,695	1,038,569	14.5	150,695
Illinois	409,556	21.3	87,211	409,556	21.3	87,211
Colorado	23,567	96.7	22,800	23,567	96.7	22,800
Arkansas, Wyoming	120,500	28.6	34,500	120,500	28.6	34,500
South Dakota	22,900	67.2	15,400	22,900	67.2	15,400
Tennessee	2,000	15.0	300	2,000	15.0	300
Total	388,842,562	12.1	46,873,932	388,842,562	12.1	46,873,932

Quantity and value of natural gas consumed in the United States in 1907, by States.

State.	Number of producers.	Consumers.		Gas consumed.		
				Domestic.		
		Domestic.	Industrial.	Quantity, M cu. ft.	Cents per M cu. ft.	Value.
Pennsylvania	344	295,115	3,812	44,840,748	24.2	$10,846,922
Ohio	468	380,489	5,476	41,970,198	24.4	10,228,979
Kansas	196	146,327	1,605	16,022,597	14.8	2,374,761
West Virginia	105	53,807	1,000	9,807,000	16	1,567,911
New York	208	83,805	155	10,466,829	27.9	2,918,817
Indiana	687	46,210	218	4,480,499	28.7	1,284,160
Oklahoma	107	11,038	277	1,262,808	19.3	244,050
Kentucky	38	19,279	239	1,028,898	31.5	324,368
Alabama	2	600	4			
Louisiana	5	3,000	38	343,261	30.7	105,272
Texas	8	1,250	6			
California	51	6,346	37	97,245	102.2	99,376
Illinois	128	2,126	61	344,304	22.7	78,284
Arkansas	6	3,899	35			
Colorado	3	1,091	21	185,405	40.5	75,182
Wyoming	4	6	3			
South Dakota	13	529	5	22,500	53.8	12,100
Missouri	26	259	12	41,340	25	10,335
Tennessee	4	1	1	400	25	100
North Dakota	3	3	....	940	25	235
Oregon	1	1	....	400	25	100
Total	2,407	1,055,181	13,005	130,915,372	23	30,170,952

State.	Gas consumed.					
	Industrial.			Total.		
	Quantity, M cu. ft.	Cents per M cu. ft.	Value.	Quantity, M cu. ft.	Cents per M cu. ft.	Value.
Pennsylvania	119,700,431	10.1	$12,070,625	164,541,179	13.9	$22,917,547
Ohio	41,001,570	12.2	4,998,801	82,971,768	18.4	15,227,780
Kansas	58,555,098	4.2	2,478,537	74,577,695	6.5	4,853,298
West Virginia	44,363,520	4.9	2,190,066	54,170,520	6.9	3,757,977
New York	1,390,925	12.9	179,716	11,857,754	26.1	3,098,533
Indiana	2,134,705	13.4	286,445	6,615,204	23.7	1,570,605
Oklahoma	3,552,828	4.6	162,892	4,815,636	8.5	406,942
Kentucky	274,260	20.3	55,808	1,303,158	29.2	380,176
Alabama						
Louisiana	944,473	7.7	73,004	1,287,734	13.8	178,276
Texas						
California	133,099	51.8	69,021	230,344	73.1	168,397
Illinois	810,040	8.1	65,293	1,154,344	12.4	143,577
Arkansas						
Colorado	581,583	8.8	51,400	766,988	16.5	126,582
Wyoming						
South Dakota	15,000	49.3	7,400	37,500	52	19,500
Missouri	66,750	10	6,675	108,090	15.7	17,010
Tennessee	1,600	12.5	200	2,000	15	300
North Dakota	....	....	....	940	25	235
Oregon	....	....	....	400	25	100
Total	273,525,882	8.3	22,695,883	404,441,254	13.07	52,866,835

Quantity and value of natural gas produced and consumed in the United States in 1907, by States.

State.	Produced.			Consumed.		
	Quantity, M cu. ft.	Cents per M cu. ft.	Value.	Quantity, M cu. ft.	Cents per M cu. ft.	Value.
Pennsylvania	135,516,015	13.9	$18,844,156	164,541,179	13.9	$22,917,547
West Virginia	122,687,236	13.6	16,670,962	54,170,520	6.9	3,757,977
Ohio	52,040,996	16.8	8,718,562	82,971,768	18.4	15,227,780
Kansas	74,526,300	6.5	4,843,019	74,577,695	6.5	4,853,298
Indiana	6,624,204	23.7	1,572,605	6,615,204	23.7	1,570,605
New York	3,287,974	23.3	766,157	11,857,754	26.1	3,098,533
Oklahoma	4,867,031	8.5	417,221	4,815,636	8.5	406,942
Kentucky	1,303,158	29.2	380,176	1,303,158	29.2	380,176
Alabama, Louisiana, Texas	1,287,734	13.8	178,276	1,287,734	13.8	178,276
California	230,344	73.1	168,397	230,344	73.1	168,397
Illinois	1,154,344	12.4	143,577	1,154,344	12.4	143,577
Arkansas, Colorado, Wyoming	766,988	16.5	126,582	766,988	16.5	126,582
North Dakota	940	25.0	235	940	25.0	235
Missouri	108,090	15.7	17,010	108,090	15.7	17,010
Tennessee	2,000	15.0	300	2,000	15.0	300
South Dakota	37,500	52.0	19,500	37,500	52.0	19,500
Oregon	400	25.0	100	400	25.0	100
Total	404,441,254	13.07	52,866,835	404,441,254	13.07	52,866,835

PROBABLE DURATION OF THE SUPPLY OF NATURAL GAS.

The duration of high pressures in the known fields is very short. There is no probability of the pressures exceeding 100 pounds per well after ten years. The rate of decline is a peculiar one. At first very rapid, it would be expected that the decline in pressure would follow a simple rate, but it does not. Many wells are still showing a slight but appreciable yield by pumping them after the pressure became negligible. The yield from these low-pressure wells is surprisingly persistent. Evidently the territory drawn upon by them is much larger than was expected. The pumping of natural gas in order to utilize the entire supply is the most hopeful element in the outlook for a continued supply. It is this feature which made possible the use of a larger quantity of natural gas last year than the year before. The outlook is that natural gas will be utilized for as long a period as has already elapsed since the industry began, with the greater part to be furnished by the Mid-Continent field.

NATURE AND EXTENT OF WASTE OF NATURAL GAS.

Waste of natural gas will be divided into three classes: First, waste incident to the discovery of a natural-gas field; second, waste in oil production; third, waste in consumption.

WASTE FROM HIGH-PRESSURE WELLS.

It has been a common experience in the discovery of a gas field to encounter pressures so great as to lead to great difficulty in capping, and thus confining the gas until needed. Noted instances of this were the Homewood well near Pittsburg, the Karg and Adams wells in Ohio, the Caney Fork well in Kansas, and, more recently, the wells of the Caddo field in northwestern Louisiana. Individual wells among these have wasted as much as 25,000,000 cubic feet per day, or sufficient gas to supply the entire consumption of three cities the size of Washington, D. C. In the Caddo field at the present time the waste of this character is estimated at 70,000,000 cubic feet per day. In this case wells are drilled through the gas-producing stratum in search of petroleum, which is usually found a few hundred feet below. The natural gas is cased off, but usually, owing to lack of skill on the part of the driller and indifference to the waste of gas, the gas escapes around the casing in increasing volume as the earth is loosened from around the pipe, and finally the force of the gas is sufficient to blow the casing entirely from the well. This has happened in four wells already in the Caddo field. When a well is thus "blown out" little effort has been made to close it. It has been the practice to set fire to the gas for an advertisement to the region.

WASTE OF GAS FROM PETROLEUM WELLS.

The production of more or less gas is incident to the drilling of all oil wells, and in most of them, by the time the petroleum-bearing sand is reached, the escape of gas is very great. Taken altogether, the waste of gas by this means is much greater and much more difficult to prevent than the waste from high-pressure gas wells.

In the first days of oil-well drilling in Pennsylvania, natural gas was a nuisance and a menace to the oil producer. This menace became greater with the volume of the gas. It developed a hostility toward natural gas on the part of the oil-well driller, which has increased rather than diminished up to the present time. It is to this hostility that the present waste of natural gas in oil regions is due. When natural gas was encountered in a sand above the expected oil stratum, it always cost considerable money to case it off and pack it in order to continue the drilling, and frequently caused explosions, tearing out the side of the well and occasionally blowing out the casing, causing the ruin of the enterprise. Every oil well now drilled includes in its outfit pipes connected with the casing for carrying the natural gas to a safe distance. Frequently it is burned to get rid of it, sometimes under the boiler to supply power for the well drilling and pumping. This practice has become so general that it is a common custom to pay $5 per twenty-four hours for the power for a well-pumping station. When the natural gas contains appreciable amounts of hydrogen sulphide, with the consequent injury to health, its presence is proportionately less welcome.

It is difficult for the oil-well driller to obtain a prompt and profitable market for the natural gas, whereas with oil it is only necessary to connect the well to a tank, and the cash for the product can be obtained within a few hours. Occasionally, when the pressure due to natural gas is greatly relieved, oil is found. The oil-well driller has accepted this exceptional case as a rule, and is apt to give all possible vent to the gas in the hope of its being followed by the desired petroleum. As to the amount of natural gas which is being wasted daily, no accurate statistics have been attempted, and the judgment of Dr. I. C. White,[a] state geologist of West Virginia, may well be accepted, to the effect that no less than 1,000,000,000 cubic feet of gas are wasted every twenty-four hours. Of this undoubtedly the larger part is wasted in the production of oil. Pumping the oil leaves the wells more or less open, and prevents any careful saving of the gas.

WASTE IN CONSUMPTION.

Directly associated with the waste of natural gas by allowing it to escape freely from oil and gas wells is the form of waste where the gas is used, by delivering it through pipes back into the ground in oil wells below the oil-bearing stratum, so that it will spray the oil to the surface. The mixture of oil and gas then runs into a tank where the oil is saved, but usually the gas is allowed free vent to the outside air. The lack of care in saving the gas after thus using it is a good example of the carelessness with this material prevalent in the oil fields.

Where natural gas is utilized for power, heat, and the lighting of dwellings and has once entered the pipe lines of the distributer, the waste is comparatively small, and little can be said at the present time in regard to any serious loss due to ineffective consumption. Much is used for lighting with incandescent mantles, an efficient use which leaves practically nothing to be desired. A still greater quantity is burned in stoves or in grates, under conditions which are also efficient. For power purposes there is little excuse for burning gas under boilers for the generation of steam, when so much greater economy can readily be produced by consuming it in internal-combustion engines, and the adoption of the gas engine in the place of steam should proceed with far greater rapidity than at present. The following table, prepared by Dr. F. H. Oliphant in 1892,[b] shows that nine-tenths of all the gas used could be saved by substituting internal-combustion engines for the kind of steam engines in use in the oil regions:

[a] Conference on the conservation of natural resources, White House, "Waste of fuel resources," p. 5.

[b] Mineral Resources, 1892.

Comparison of fuel per indicated horsepower per hour for different types of engines.

Type of engine.	Cubic feet of gas.
Large natural-gas engine, highest type	9
Ordinary natural-gas engine	13
Triple-expansion condensing steam engine	16
Double-expansion condensing steam engine	20
Single-cylinder and cut-off steam engine	40
Ordinary high pressure, without cut-off, steam engine	80
Ordinary oil well pumping steam engine	130

METHODS OF PREVENTING OR LESSENING THE WASTE OF NATURAL GAS.

What has been said above concerning the substitution of gas engines supplied with natural gas, for furnaces burning natural gas under steam boilers, is a matter of small moment compared with the prevention of escape of natural gas into the air. Our total consumption of natural gas in the United States in 1907 was 404,000,000,000 cubic feet per year, whereas the amount wasted—not burned at all—was estimated at practically the same amount. Thus only half of all the natural gas actually produced goes to any useful purpose. This waste should furnish light for half the urban population of the United States. Remedy for this waste by legislation has been extremely effective in Indiana, Ohio, and Pennsylvania. Only a part of the credit for stopping natural-gas waste is due to legislation, much credit being due to the natural-gas companies themselves for taking the initiative in this reform and carrying it out with most commendable vigor. As a result, the waste of natural gas in these States has practically ceased. Great precautions are now used for the suppression of every flambeau or open gaslight. They are only to be seen at the present time occasionally in connection with the drilling of oil wells. These precautions in late years have not been due so much to legal restrictions as to the efforts of the natural-gas distributers to economize in every direction in the saving of natural gas. The laws of Pennsylvania, West Virginia, Ohio, and Indiana call for the efficient capping of every natural-gas well when not in use. This, however, does not prevent the escape of natural gas where it is an incident of oil production. In this field a more practical plan will depend on the cooperation of the natural-gas and oil-collecting companies, by which the oil producer may receive pay promptly for natural gas to be collected by the natural-gas companies from his oil well. In West Virginia the oil-collecting companies and the natural-gas collecting companies are usually simply branches of the same company, and this plan of collecting gas from the oil wells is already being carried into effect.

The ingenuity and watchfulness of the natural-gas companies has effected far greater saving in natural gas than was believed possible five years ago. The result is in evidence from the gain in production in Pennsylvania and West Virginia, where high pressures have practically ceased.

EXTENSION OF NATURAL-GAS SUPPLIES.

PREVENTION OF WASTE IN EXTRACTION AND IN USE.

It is of prime necessity that the laws concerning the capping of natural-gas wells, which have had such good effect in the principal oil and gas producing States, should be extended to the newer fields in the Southern and Southwestern States, and that the most radical measures should be taken to promptly suppress the great waste in these fields at the present time. When effective laws are in operation controlling the escape of gas from high-pressure wells, the problem will be reduced to saving the gas from the oil wells—a problem which can be solved only by affording a prompt and efficient market for the gas, even when produced in small quantity. Meantime, the problem of compressing natural gas in steel cylinders for small-scale transportation is receiving much consideration. Within the next few years success will undoubtedly be attained in returning the natural gas to reservoirs within the earth, which have proved to be sufficiently tight to hold the gas under heavy pressure. Experiments in this direction, costing more than $125,000, are being carried out in Ohio.

INCREASING EFFICIENCY IN USE.

This has already been sufficiently referred to in a previous paragraph. (See pp. 59–60.)

DISCOVERY AND DEVELOPMENT OF SUBSTITUTES.

Unlike petroleum, natural gas can be replaced efficiently, at least for all practical purposes, by fuel gases produced by methods which are already well understood and are being studied with great care by the technologic branch of the United States Geological Survey. This substitution of fuel gas is well understood. The replacement of the artificial gas for the natural will regularly follow the trade relation of price. It is known that many large culm banks and other amounts of refuse coal are already owned by the natural-gas companies in anticipation of their utilization at the place where they occur, for making and distributing gas to distant points of consumption. This long-distance transportation of natural gas has been developed on so large a scale between West Virginia and Cleveland, Ohio, that the transmission of fuel gas over long distances is now also being studied as a certain feature of future industrial progress.

PEAT RESOURCES OF THE UNITED STATES, EXCLUSIVE OF ALASKA.

By Charles A. Davis.

Peat as a source of fuel and power, as well as the raw material upon which may be based a number of industries, has but recently attracted general attention in this country. It has, however, long been used in northern Europe, where it is estimated that in the neighborhood of 10,000,000 tons prepared in various ways are consumed as fuel annually, and smaller amounts are used as stable litter, for sanitary purposes, and in various trades and arts.

It has been assumed by engineers, economists, economic geologists, and others, because of the abundance and cheapness of good coal and wood in the United States, that peat could not be used profitably in competition with them, at least for a long time to come.

Recent developments in the utilization of low-grade fuels in producer-gas engines, and the very considerable successful use of peat for the generation of fuel, illuminating, and producer gas in Sweden, Germany, Russia, and other countries of Europe, have made a marked impression on those scientists and others in America who have followed the march of events in this direction, and these developments have aroused new interest in the possibility of using peat as an auxiliary fuel.

Already preliminary experiments have been made by the technologic branch of the United States Geological Survey with a large gas producer, which confirm the reports of foreign success in this direction, showing that some peats of American origin are little inferior to many grades of bituminous coal now on the market, and superior to some in the quantity of producer gas to be derived from them and in the calorific value of the gas.

Still more recent than this work is the report from Germany that by the investigations of Doctors Frank and Caro it is possible to recover a large part of the combined nitrogen contained in peat, while it is being converted to gas in the gas producer, as ammonium sulphate; and that where the nitrogen is present in amounts slightly above 1 per cent of the dry matter of the peat, the quantity of ammonium sulphate obtained pays the expenses of maintaining the plant, of gasifying the peat, and a profit besides, leaving the gas as an additional profit. As many American peats have more than 2 per cent of combined nitrogen and a considerable number of analyses show above 3 per cent, it is probable that in the near future peat beds will be profitably utilized for the production of power and ammonium salts in the United States.

This is the more likely when it is considered that the region of most abundant occurrence of peat in large deposits lies along the northern border of the country and in the eastern Coastal Plain. There are also smaller areas where it is found, as in the western mountains and in the moister portions of the Pacific slope. The States containing the greatest amount of peat are the eastern Dakotas, Minnesota, Wisconsin, Michigan, northern Iowa, Illinois, Indiana and Ohio, New York, the New England States, New Jersey, the coastal portions of Virginia, North and South Carolina, Georgia, and practically all of Florida. It is also assumed that there are workable peat beds in the swampy parts of the Gulf States and in those portions of the flood plain of the Mississippi remote from the stream.

It will be noted that these regions of frequent occurrence of peat are practically all outside of the coal fields, with the exception of Michigan, where, as is well known, the coal basin has not been found to be productive except in limited marginal areas, very small in comparison with that of the entire basin.

As a sign of the times it may be stated that work is about to begin in Florida on a plant for generating electric power by producer-gas engines using air-dried peat as fuel, the power to be transmitted to Jacksonville. Aside from other phases of the question it should be remembered that peat can be mined and prepared for the gas producer by the simplest and most inexpensive equipment, and with a minimum of danger, since all of the workings are open cuts made by the use of spades or by ordinary excavating or dredging machinery, so that none of the dangers of underground mining are encountered.

On the other hand, the great drawback in the preparation of peat for fuel or other uses has always been and continues to be the fact that it contains from 85 to 90 per cent or more of water as it comes from the beds, and that the greater part of this water can not be pressed out but must be removed by evaporation. Peat which is air dry contains from 15 to 25 per cent of water, and its theoretical efficiency is lowered thereby in nearly direct proportion to the amount of water present.

In gas producers of recent types, however, it is reported that peat with 40 per cent water has been used with success, and for this purpose the question of excess of water has apparently been solved by plowing or digging up the peat and allowing it to dry out by exposure to the wind and sun on the surface from which it is taken.

In Florida, even in midwinter, peat taken from below the water level, ground in a pug mill, and afterward spread over a drying ground in a layer 8 inches thick, dries to the air-dry state in about three weeks, and is ready for use in a gas producer in less time.

The question of artificially drying peat for fuel has received and is now engaging the attention of able engineers and inventors, and, in the opinion of many, the successful solution of this problem is necessary before any considerable increase in the use of peat for ordinary fuel can be expected.

Briefly stated, success depends on finding a way to handle a ton of peat with about 90 per cent of water so rapidly and cheaply that the 250 pounds of salable material, which will result when it has reached the air-dry state, will pay the cost not only of the processes of preparation, but also of management, amortization, and selling, and return a profit on the original investment. Attention should be called to the fact that if peat with 90 per cent water has its moisture content reduced to 80 per cent, it loses more than half of its content of water, and that this amount is readily extracted by very simple and inexpensive processes.

In Europe, peat is prepared for fuel in several ways designed primarily to render it transportable and efficient as a source of energy. As cut peat it is used extensively for domestic purposes in the form of air-dried sods or blocks cut by hand with specially designed spades. A more compact and efficient fuel is made by more or less thoroughly macerating the peat and pressing it into molds, after which it is dried by spreading the blocks on the ground, exposed to sun or wind, or by grinding it in a specially constructed pug mill similar to that used in grinding clay for making bricks. The peat is ground wet as it comes from the beds, and delivered from the mill in the form of wet bricks, which on exposure to the air and sun's heat for some time become dry, firm, tough, and nonabsorbent. This is machine peat, which is rated the most generally successful form of peat fuel for domestic and boiler use on the markets of Europe. As marketed, this product contains from 20 to 25 per cent of moisture and has, theoretically, about 65 per cent of the fuel value of the same weight of good bituminous coal when burned in stoves or under boilers, but practically, because of the lack of waste of the peat, in the form of ash, smoke, clinker, and unconsumed portions, its real value is higher than is indicated by comparison of the possible heat units to be obtained.

As peat briquets the material is more compact, burns more slowly and persistently, and stands transportation and handling well. The peat is dried thoroughly, powdered, and briquetted, either without or with a binder or in mixture with coal or lignite.

An increasing amount of peat is manufactured into charcoal or peat coke, especially in Germany, where it is used somewhat extensively as a substitute for wood charcoal in smelting iron and in other metallurgical processes, including the refining of copper, steel making, etc. Of the processes so far developed for the manufacture of peat coke none have proved profitable on a commercial scale, except such as condense the distillates and recover a series of by-products similar to those obtained by the destructive distillation of wood, viz, fuel gases, methyl alcohol, acetic acid, lime acetate, ammonium salts, tar and its derivatives. This process involves large preliminary investment and the maintenance of costly plants, but where a good market can be found for the by-products this seems to be justified, according to unbiased and trustworthy reports from Europe. In preparation for coking, the peat is treated exactly as if it were to be sold as machine-pressed peat and is stored in open sheds until needed for the coking retorts.

An increasing amount of peat in the form of powder burned with blast burners is used abroad for firing under boilers and in brick and cement burning; where properly prepared and rightly fired it approaches theoretical efficiency when used in this way.

The production of gas from peat, as has been stated, has passed beyond the experimental stage, and peat gas is used for metallurgical purposes, boiler firing, making lime and brick, and to some extent in making glass, while a rapidly growing number of producer-gas plants for using peat are being installed for generating electric power for transmission directly from the larger peat deposits to centers of use.

In view of all of these considerations the following estimates of the peat resources of the United States have been prepared with the view of at least directing attention to the very considerable source of wealth to the nation which is now lying entirely undeveloped in the swamps and bogs of the country. It will also be noted in considering the possibilities of the peat deposits that they furnish potential substitutes for wood in various departments of industry, and in some considerable degree in these directions may relieve the drain upon the vanishing forests.

In making the estimates given below it has been the aim of the writer to be conservative in every detail, and it is believed that in no case will they be found too optimistic.

The total swamp area of the United States, exclusive of Alaska, is estimated to be 139,855 square miles.[a] Of this 8 per cent is assumed to have peat beds of good quality, or 11,188 square miles. The peat in this area is assumed to average at least 9 feet in depth and to contain 200 tons of dry fuel per acre for each foot in depth, or a total of

[a] Sixtieth Congress, first session, S. Doc. 151.

12,888,500,000 tons. Its value, if converted into machine peat bricks at $3 per ton, would be $38,665,700,000. The value if coked and the by-products of distillation saved would be as follows:

Quantity and value of peat coke and by-products from peat deposits of the United States.

	Product in tons.	Value.
Peat coke	3,608,800,000	[a]$26,005,300,000
Illuminating oils	257,800,000	4,474,200,000
Lubricating oils	90,200,000	
Paraffin wax	38,700,000	3,479,900,000
Phenol	167,500,000	66,345,100,000
Asphalt	25,800,000	824,900,000
Wood alcohol	43,800,000	7,844,000,000
Acetic acid	56,700,000	2,268,800,000
Ammonium sulphate	39,900,000	2,777,400,000
Combustible gases	738,400,000	6,501,300,000

[a] Charcoal price. At coke price the value would be $9,924,200,000.

The better grades of peat coke are nearly free from sulphur and phosphorus, and may be used wherever hard-wood charcoal is required. The quantity of wood required to make charcoal equivalent to the amount of the peat coke given in the estimate would be approximately 8,019,800,000 cords. The uncondensable gas given off from the retorts while the peat is being converted to coke has good fuel value, the maximum being about 300 B. t. u. per cubic foot, and has been successfully used for heating the retorts and for other fuel purposes.

If converted into producer gas by the most recently developed processes, so that the combined nitrogen of the peat is converted into ammonia and fixed as ammonium sulphate, there would be possibly available 619,257,511,000,000 cubic feet of producer gas, with a calorific value of 145 B. t. u. per cubic foot. Assuming 1.5 per cent of nitrogen as an average content of the peat, which is low, since many analyses show more than 3 per cent, 100 pounds of ammonium sulphate to the ton of peat treated in the gas producer could be obtained. On this assumption there is stored up nitrogen enough in the peat to supply at least 644,400,000 tons of ammonium sulphate, having a value of $36,732,400,000, in addition to the gas produced.

Recent tests reported from Europe show that from 2 to 2.5 pounds of peat will produce an effective horsepower per hour, if reduced to gas in a properly designed gas producer and used in the gas engine. Taking the larger amount, to be conservative, it is evident that there is stored up in the peat beds of the country, as estimated above, energy sufficient to develop 10,310,860,800,000 effective horsepower hours.

In Europe great quantities of the more fibrous types of peat are manufactured into stable litter, for bedding live stock, and peat mull, or powder, for absorbent and sanitary uses. Of this class of material it is estimated that there are at least 2,578,000,000 tons available.

This class of material is superior to straw and other substances now generally used for the purpose, and would readily bring $10 per ton, or the whole amount has a prospective value of $25,780,000,000. The only factory (located in Indiana) now making a product of this class in the United States sells its entire output of several hundred tons per annum at about $12 per ton.

A single plant for making paper from peat is in operation in Michigan. Possibly 5 per cent of the total amount of the peat of the country is suitable for this purpose, or 644,400,000 tons. The use of this material would reduce the consumption of wood for the purposes of making coarse papers and pasteboard, by whatever amount it displaced wood pulp in the manufacture of such materials.

In the United States peat is being somewhat extensively manufactured into fertilizer filler, material used in making various grades of artificial fertilizers in which slaughterhouse and other refuse animal matter rich in nitrogen are ingredients or in which hygroscopic mineral compounds are used. Peat in the form of dry powder is especially adapted to this use, since it absorbs water and ammonia readily, is a deodorizer, and to a considerable extent prevents fermentation and decomposition. At the prices now obtained for peat suitable for this purpose in the form of dry powder, and considering one-half of the total amount suitable for the purpose, its value is estimated to be $38,666,000,000, or about the same as the valuation of the whole for ordinary fuel.

Ethyl or "grain" alcohol has been made from the less thoroughly decomposed peats in Denmark and Sweden at a cost estimated at about 47 cents per gallon.

If 10 per cent of the entire body of peat in the country can be used in this way, about 70,900,000 tons of alcohol can be obtained from peat. It must be said in passing that this process is as yet hardly past the experimental phases.

Artificial wood, a fireproof or slow-burning composition of peat and mineral cements, has been made in Germany on a small scale for paving blocks and similar uses, as well as for larger structural purposes, as a substitute for wood or stone in buildings. About 10 per cent of the entire peat deposits of the United States may be suitable for this composition, or 1,288,800,000 tons, the use of which would release an equivalent amount of sawed lumber for other uses or to be held in reserve against future need.

Fibrous peat, properly cleansed of the finer material associated with it, is finding a constantly growing use in Europe as packing material for fragile or perishable articles, and for protecting and insulating water and other pipes subjected to the liability of freezing. The peat best adapted to this use is too light in weight and too loose in texture for fuel manufacture, and may be estimated to occur to the amount of 500,000,000 tons, with a market value of $3,000,000,000, displacing excelsior, hay, straw, paper, and other similar materials which are now used.

Fabrics of various qualities and kinds, mattresses for hospitals, and fiber for surgical and other asceptic dressings and as a substitute for silk in cloth weaving have been made from certain grades of peat, but the market is so well supplied with other products for the same purpose, which are of as good or better quality, that the use of the peat products has never reached any extensive commercial scale and does not seem likely to do so in the near future.

It is clearly apparent, however, that in the peat beds of the United States there lies undeveloped—even entirely untouched—a vast amount of raw material from which may be derived, by intelligent and conservative exploitation, fuel, power, fertilizing material, and the raw materials from which may be made a number of valuable products, all of which will serve to supplement other resources which are now known to be limited in quantity. By utilizing these resources also the wealth of the nation may be possibly increased by the not inconsiderable sums which represent the potential cash value of the peat beds and their products, and an equivalent amount of other material will be rendered free for other purposes.

ABSTRACT OF ESTIMATE OF THE PEAT RESOURCES OF THE UNITED STATES.

Peat, a fuel used in Europe to the amount of 10,000,000 tons per annum, is an almost unknown material in the United States, although possessing properties which make it an excellent domestic fuel and desirable for gas production on a large scale.

As the area of the peat beds in the United States, and the quantity of workable material which they contain, is almost unknown, the estimates submitted are but rough approximations. The following are sources of information used here: (1) Publications and topographic maps of the United States Geological Survey; (2) reports of the state geological surveys of New York, Michigan, Iowa, Indiana, Massachusetts, and New Jersey; (3) cooperative reconnaissance peat surveys undertaken by the United States Geological Survey and the state surveys of Connecticut, Maine, and Wisconsin; (4) personal observation of the writer in various parts of the country.

The total area of swamp land is estimated by the United States Geological Survey [a] to be 139,855 square miles. The writer estimates 8 per cent of this to have peat beds which would average 9 feet deep, or 11,188 square miles, with an average possible production of 200 tons of dry fuel per acre-foot, or a total of 12,888,500,000 tons.

[a] Sixtieth Congress, first session, S. Doc. 151.

The greater part of this material occurs in that part of the country without productive coal fields, in eastern North and South Dakota, Minnesota, Wisconsin, Michigan, New York, and the New England States, in northern Iowa, Illinois, Indiana, Ohio, in the coastal plain region, in eastern New Jersey, Virginia, North and South Carolina, Georgia, and the whole of Florida. The swamp areas of the Gulf States and of the flood plain of the Mississippi River, as well as those of the Pacific States, also contain workable peat beds, but in none of these is there any considerable overlapping of the peaty areas into workable coal fields.

It is estimated that, in the vicinity of the beds, this quantity of peat would have a value of $3 per ton in the form of air-dry blocks, or a total of $38,665,700,000, and that once established on a commercial basis the entire product would find ready sale as fast as produced. If this peat were all used in by-product gas producers, to this value as fuel may be added the value of 644,400,000 tons of ammonium sulphate, which at present prices would be worth $36,732,400,000.

Peat has been successfully used as a source of producer gas, of a form of charcoal or coke, of various by-products from the coke retorts similar to those obtained from wood distillation, of fuel and illuminating gas, of fertilizer filler, of paper, of litter for stables, and of packing materials. In these forms the prospective value of the total peat of the country is much larger than as peat fuel.[a]

[a] For a fuller general discussion of the origin, handling, and uses of peat, see Bastin, E. S., and Davis, C. A., Peat deposits of Maine: Bull. U. S. Geol. Survey No. 376, 1909, pp. 8–64.

IRON ORES OF THE UNITED STATES.

By C. W. Hayes.

INTRODUCTION.

No previous inventory of the iron-ore supplies of the United States in any detail has ever been published, and the present one must be considered only a first approximation which will be materially modified as new quantitative data are made available by future public and private investigations. The estimates of ore supplies given in this paper are not based upon the judgment of any individual, but so far as possible represent the consensus of opinion of those best qualified to form an opinion. Cordial cooperation in making up the estimates has been given by officers of private corporations and the several state geological surveys and by economic geologists and mining engineers generally. Special acknowledgments are due to Messrs. W. N. Merriam, C. K. Leith, D. H. Newland, H. M. Beuhler, W. S. Bayley, T. L. Watson, R. C. Hills, and J. F. Kemp, who have furnished information which could not have been obtained from any other source.

CHEMICAL CLASSIFICATION.

The commercial ores of iron, on the basis of chemical composition, fall into two main classes, i. e., oxides and carbonates. The latter class is relatively unimportant, furnishing in the United States less than one-twentieth of 1 per cent of the annual production. The oxides are further separated, according to the proportion of oxygen and combined water which they contain, into three classes. The chemical and commercial classification is therefore as follows:

1. *Magnetite.*—Magnetic oxide, Fe_3O_4, including titaniferous magnetite. Theoretical iron content, 72.4 per cent. Generally containing some hematite.

2. *Hematite.*—Anhydrous sesquioxide, Fe_2O_3, including specular and red hematite, red fossil ore, oolitic ore, etc. Theoretical iron content, 70 per cent.

3. *Brown ore.*—Hydrous sesquioxide, $Fe_2O_3nH_2O$, including turgite, limonite, goethite, or a mixture of these minerals, known locally as brown hematite, bog ore, etc. Theoretical iron content, 59.8–66.2 per cent.

4. *Carbonate.*—Siderite, iron carbonate, $FeCO_3$, known locally as spathic ore, black band ore, kidney ore, etc. Theoretical iron content, 48.2 per cent.

GEOLOGIC CLASSIFICATION.

In their geologic relations and mode of occurrence the iron ores may be further classified as follows:

1. *Magmatic segregations in basic igneous rocks.*—The titaniferous magnetites of the Adirondack region represent this type. A characteristic of such deposits is the perfect gradation from the ore into the surrounding rock by an increase in the gangue, which consists of the same minerals as the associated igneous rock. The deposits are of great size and present large possibilities of utilization by concentration or with modification of furnace practice which will permit their economical reduction.

2. *Contact deposits, formed in connection with the intrusion of igneous rocks at their contact with the intruded sediments, generally limestones.*—These appear to be due to ascending heated waters and vapors given off by the cooling igneous rock. The ores include both magnetite and hematite. Typical examples are the Cornwall deposits of Pennsylvania and many of the western iron-ore deposits, as those at Hanover, N. Mex., and Iron Springs, Utah.

3. *Concentration deposits.*—These include all forms of the oxide ores in which the iron, originally disseminated through the rocks, has been dissolved, transferred, and redeposited by circulating waters. It includes most of the brown ores of the Appalachian region in which the iron was originally disseminated through a great mass of limestones and shales and has been leached out and concentrated by surface waters during the erosion of these rocks. In some cases the iron was probably deposited as carbonate or sulphide and subsequently changed in place to hydrous oxide. It includes the bog-ore deposits, which have been formed or are now forming in swamps, to which iron is brought in soluble form as organic compounds and precipitated by the breaking up of those compounds through oxidation.

4. *Replacement deposits.*—These are closely related to the concentration deposits, the principal difference being that the ore-bearing solution has derived the iron from an outside source and deposited it in place of some definite portion of an original rock series, generally a limestone. They include all classes of ores, both oxides and carbonates, their composition depending on the conditions of deposition and the subsequent alterations which they have undergone. An example of this type is the so-called Oriskany ore of Virginia. In this case the iron derived from a great mass of overlying shales has been carried in solution, and where structural conditions were favorable

deposited in place of a certain easily soluble bed of limestone for a variable distance from its outcrop.

5. *Bedded deposits.*—These include all deposits in which the ore forms tabular or lenticular bodies which lie parallel to the bedding or foliation of the inclosing rocks. Their origin may be diverse, but their common characteristic is great lateral extent compared with thickness. In many bedded deposits, though not in all of them, the ore is sharply differentiated from the surrounding rocks. Magnetite deposits of this type are the Adirondack ores associated with metamorphic sediments and with gneisses of uncertain origin. Of the hematite deposits of this type are the enormous deposits of the Lake Superior district, where certain beds of the iron formation have been enriched both by the removal of silica in solution and by the deposition of additional iron. It also includes the gray specular ores of Alabama, which are associated with Cambrian and pre-Cambrian slates and sandstones, and the important red ores, fossil and oolitic, which form regular sedimentary beds, differing only in composition from associated Silurian sandstones and shales. Of the carbonates it includes the black-band ores, which occur as layers of nodules or continuous beds associated with the "Coal Measures" in Ohio and Pennsylvania.

6. *Gossan deposits.*—Iron sulphides tend to oxidize with loss of sulphur when exposed to surface weathering, and deposits of pyrite and pyrrhotite are therefore generally covered with a deposit of residual brown ore, which extends down to the level of permanent ground water. Examples of this type are the brown ore on the outcrop of the pyrrhotite veins at Ducktown, Tenn., and the iron-ore capping of many metalliferous veins in the West.

Referred to the ultimate source of the material, it may be stated in general that the iron ores are derived from the iron minerals either segregated or disseminated in igneous rocks or the iron minerals deposited by igneous emanations, which have been worked over in varying degrees by the agents of weathering and sedimentary and chemical deposition at the surface of the earth. Iron compounds are among the most stable substances under surface conditions, and hence the net result of the changes at the earth's surface is to concentrate iron minerals mechanically and chemically as compared with associated minerals.

VALUE OF ESTIMATES.

An understanding of the above chemical and geologic classifications of iron ores is essential for an appreciation of the limitations and uncertainties of any estimate of the ore supplies of the country. It will be readily understood that with the great diversity in type of deposits there must be a very wide difference in the degree of accuracy with which the ore can be estimated. The closest approximation can be made in case of bedded deposits such as the Clinton red hematites. These beds vary in thickness and composition from place to place, but the variations are similar to those characterizing other sedimentary beds such as coal, and with a minimum amount of testing on the outcrop and at depth their contents can be calculated with a fair degree of certainty. Certain assumptions, however, must always be made. Thus it is assumed that observed variations in composition and thickness continue with regularity between and beyond points of observations; also that a certain depth will limit workability. This limiting depth will depend upon a variety of conditions which can not be determined in advance of mining, and hence the depth fixed upon in making calculations will be largely a matter of opinion, and must be expected to change with changing commercial conditions. Hence it is doubtful if even the best known and most thoroughly tested deposits of red hematite can be estimated within 10 per cent of their actual yield. At the other extreme are the concentration deposits of brown ore. These are extremely variable both in depth and horizontal extent. Surface indications are thoroughly unreliable, and those most experienced in working such deposits are practically unanimous in the opinion that no deposit can be safely estimated until every ton of ore has been mined. Under such circumstances the estimates given below of ore remaining in this class of deposits can only be regarded as having a degree of accuracy represented by a factor varying between 0.7 and 3.

Intermediate between these extremes are the most important deposits, including those of the Lake Superior and Adirondack districts. The former by reason of their greater regularity and the thoroughness with which they have been tested may be considered as known within 15 or 20 per cent. The latter are much less fully tested, and estimates of their probable yield are based upon assumptions which further development may prove to be erroneous. Estimates of the western ore deposits vary in value because of inherent uncertainties due to the nature of the deposits and to the very unequal information concerning different districts.

AVAILABILITY.

Any estimate of the iron-ore supplies of the United States must separate the ores into two classes on the basis of availability. This separation is difficult, and opinions vary widely as to where the line should be drawn. Evidently the question is one of costs: (*a*) The cost of the ore delivered at the furnace and (*b*) the cost of reduction. Actual production, past and present, being determined by the interaction of various factors, affords the best criteria of availability.

The two factors which enter most directly into the cost of ore at the furnace are accessibility and mining conditions. Many iron-ore deposits are known in regions so remote from fuel supply and from transportation lines that they may be considered unavailable at present or so long as they are compelled to compete with more accessible ores. At the same time they must be taken into account in considering the total reserves, for accessibility is only relative and no deposit, if sufficiently large to warrant the expenditure necessary for constructing roads, can be regarded as permanently inaccessible. Distance from fuel is, of course, a more serious drawback than absence of present means of transportation, while those supplied with water transportation will bear a longer haul than those carried entirely by rail.

Mining conditions may be such as to make the cost of raising the ore prohibitive at present. Such conditions are limiting depths beyond which mining, on account of the amount of water, may become very expensive, or thinness of the beds which necessitates a large amount of dead work. These conditions apply particularly to the Clinton ores and explain the difference between the total amount proved in these deposits and the amount considered at present available. Many deposits of brown ore can be worked cheaply in open pits for a certain distance from the surface, while the cost of stripping or of timbering to hold back the inclosing clay prevents their working to greater depths.

Another kind of limiting conditions arises from the fact that in many cases the ore is mixed with foreign material from which it must be separated. Thus many of the brown ores consist of small concretions scattered through clay, and a large amount of material must be passed through the washer to obtain the ore in suitable condition for the furnace. The ratio of ore to clay in deposits now being worked varies from 1:5 down to 1:20. When conditions permit the lowering of this ratio still further, large quantities of ore will be available in material which can not now be worked at a profit. Similar conditions control the availability of many of the magnetic deposits, except that here the objectionable elements are other minerals that are closely associated with the iron and must be separated by magnetic methods. The concentrated material is a high-grade ore, and the ratio of available to nonavailable in these deposits depends wholly upon cost of the process of concentration which they will bear in competition with other ores.

The second consideration affecting availability is the character of the ore itself. The content of metallic iron in ores used at present varies from 30 to 65 per cent. This wide variation is due in part to the nature of the other elements in the ore and in part to advantageous location. Thus the Clinton ores, containing as low as 30 per cent iron, can be used with advantage, because the lime which they contain makes them practically self-fluxing. At the same time they must be used near the point of production, since the low content of iron will not permit long transportation in competition with richer ores. On the other hand, siliceous ores containing less than 40 per cent iron are not considered at present available unless their location near the fuel is exceptionally favorable, since the cost of transportation per unit of iron is excessive and since a large amount of fuel is required to remove the silica. But there are enormous quantities of siliceous ore carrying from 35 to 40 per cent iron, particularly in the Lake Superior district, and this must be taken into account as a future reserve, though not at present available.

In the case of the titaniferous magnetites the ratio between the available and not available is difficult to determine. While these ores have been used only to a limited extent because of the difficulties attending the fluxing of the titanium, it seems probable that these difficulties will be overcome and a much larger use made of them either by employing a special flux in the furnace or by reducing the percentage of titanium in the charge by concentration or mixing with nontitaniferous ores.

The percentage of other constituents, such as phosphorus, sulphur, copper, chromium, manganese, and alumina, will determine the method and cost of reduction and the quality of the resulting iron. Hence these constituents, some of which are highly deleterious, may determine the question of availability by limiting the conditions under which the ore can be reduced or the product used.

Another factor is the nature of ownership. Where a large corporation controls a variety of ores and is equipped to assemble them and form any desired mixture or grade, ores may be used with advantage which would not be available if held by a smaller company not in a position to control the situation in a large way or compelled to dispose of a single kind of ore in the open market.

Because of the varying importance of these factors, future availability will obviously vary in a corresponding degree and the advantage which one district now possesses may pass to another. As the higher-grade ores of the Lake Superior region become depleted the lower-grade ores will be called upon with consequent increase in cost of transportation and smelting. The low-grade ores of the southeastern district, at present competing with the high-grade Lake Superior ores, will then have a decided advantage because of proximity to fuel supply.

The notable present tendency in the iron industry is the lower average iron content in the ores used. This tendency will undoubtedly continue in the future as the more easily accessible portions of the richer deposits are worked out. As a corollary to this is the observed tendency toward a decentralization of the iron industry, and with a decrease in the iron content of the ore used, involving a corresponding increase in cost of transportation per unit of iron, there will be an increase in the proportion of fuel which goes to the region producing the ore. This will be accompanied by the general adoption of by-product coking. It is an instructive fact that in certain furnaces now operating in the Lake Superior district the profit corresponds approximately to the value of the by-products from the coke ovens.

In making estimates all of these considerations, together with the best forecast that can be made of conditions as they will exist in the next ten years, have been taken into account in determining the ratio between available and nonavailable supplies.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION.

Iron being one of the most abundant elements, fourth in order of abundance, its natural compounds are found in practically all rocks and soils. To constitute an ore, however, certain of these minerals must be segregated into deposits of sufficient size and purity to permit economical working. Such deposits, considering the entire area of the country, are relatively infrequent. Iron ore is at present produced in only 29 of the 47 States and Territories, and about 79 per cent of the production (1907) was from two States—Minnesota and Michigan. It is evident that the distribution of the deposits is extremely uneven.

For convenience of description of the ores and discussion of the estimates the known ore deposits will be taken up by groups based on distribution and kind. A few deposits are not included in any of these groups, but the total tonnage of ore which they contain is so small as to be negligible in an estimate of the total for the entire country. The groups of deposits to be considered are the following: (1) Lake Superior ores; (2) Adirondack ores; (3) Clinton ores; (4) Appalachian metamorphic ores; (5) Appalachian brown ores; (6) Appalachian carbonate ores; (7) West Tennessee brown ores; (8) East Texas brown ores; (9) Ozark ores; (10) Rocky Mountain metamorphic ores; (11) Igneous contact ores.

(1) LAKE SUPERIOR ORES.[a]

GEOLOGIC RELATIONS.

The Lake Superior ores, chiefly hematites with subordinate amounts of magnetite, furnish approximately 80 per cent of the annual iron-ore production of the country. The total production from the region from its opening to the close of 1907 has come from the ancient folded

[a] Based on information furnished chiefly by C. K. Leith.

and metamorphosed pre-Cambrian formations in Michigan, Minnesota, and Wisconsin in proportions shown in the following table:

Geologic sources of Lake Superior iron ores.

State.	District.	Geologic horizon.		
		Keewatin.	Middle Huronian.	Upper Huronian.
		Per cent.	*Per cent.*	*Per cent.*
Minnesota (46.555 per cent)	Mesabi			39.45
	Vermilion	7.105		
Michigan (50 per cent)	Gogebic			12.24
	Marquette		21.90	.50
	Menominee, including Crystal Falls, Iron River, etc.			15.46
Wisconsin (3.308 per cent)	Penokee			1.98
	Menominee (Florence)			1.26
	Baraboo			.068

The iron formations are sedimentary deposits, usually interbedded with slate, quartzite, dolomite, and sometimes with basic extrusives. They consisted originally of chert, containing beds of iron carbonate or of dark-green ferrous silicate granules, called greenalite. As a result of surface oxidation of the iron carbonate and greenalite, the great bulk of the formation within the zone of observation now consists of chert minutely interbedded with limonite or hematite, giving a banded rock variously called ferruginous chert, taconite, or jasper. The average proportion of iron in these siliceous rocks is between 25 and 37 per cent. Numerous slate layers form subordinate proportions of the iron formation.

The iron ores constitute concentrations of ore in the exposed parts of the iron formation, produced mainly by the leaching out of the associated silica, thus leaving the iron in larger percentage, but also partly by solution, transportation, and redeposition of the iron when it was still in its soluble ferrous condition. The agents of alteration are surface waters carrying oxygen and carbon dioxide. The accessibility to the iron formation of these agents therefore determines the location, shape, and size of the ore deposits. The most favorable condition of accessibility is given by wide area of exposure of the iron formation, which is in turn a function of the dip. The flat-lying formation in the Mesabi Range exposes a greater surface to concentrating agents than the steeply dipping formation of similar thickness and character in the Gogebic range, with the result that the proportion altered to ore is much greater in the Mesabi district. A comparison of the actual areas of the different iron formations with their total shipments to date, and with their probable reserves, shows a very close relation between area and amount of ore developed. Also determining accessibility of the concentrating agents to the iron formation are numerous structural conditions, such as joints or faults or impervious pitching basements, favorable to rapid circulation of water. Finally, the texture of the iron formation itself, whether dense or porous, may determine the activity of the circulation of the waters.

It is therefore apparent that the size, shape, depth, and structural relations of the Lake Superior ores are in widest variety. In the flat-lying formations of the Mesabi range the ore bodies have wide lateral extent as compared with depth, extremely irregular outlines partly controlled by jointing, abut irregularly on bottom and sides against unaltered portions of the iron formation, and when the glacial overburden is removed are accessible to surface operations with steam shovels. In steeply dipping beds they have greater vertical as compared with horizontal dimensions, usually abut not only against unaltered parts of the iron formation, but against well-defined impervious walls consisting of slate, quartzite, dolomite, or bosses or dikes of greenstone, and in such beds underground mining is necessary. The maximum depth to which mining has extended is a little over 2,000 feet; the maximum horizontal extent thus far worked in a single mine is less than a mile, but deposits are known to connect for nearly 10 miles. An adequate summary of the variety of structural features of the several districts can not be made within the limits of this paper.

CHARACTER OF THE ORES.

The hematites and limonites making up the great bulk of the Lake Superior ores range in texture from soft and powdery to hard and crystalline. Both kinds usually have large pore space, due to the removal of silica by leaching. Locally, however, where the ores have been buried deeply in the zone of rock flowage, they have become dense, schistose, specular hematites and magnetites lacking pore space. Where the iron formation has been intruded by large masses of igneous rocks the ores are magnetic. The ores range in grade from above 60 per cent in iron down to 25 per cent in the lean parts of the iron formation. The average shipment for 1906 for the entire region was 59.8 per cent in iron. The difference between the iron ore and the iron formation is simply in the proportion of silica present.

The ores mined in the Lake Superior region to date have generally run above 50 per cent in iron. The lowest grade shipped has been about 40 per cent, in the case of local ores in demand for mixtures and favored by cheap mining and transportation. In mining much material running 40 per cent or even less is taken out and mixed with higher-grade ores to give a medium grade. Such low-grade material therefore does not figure obviously in the production. The percentage of iron in the ore mined from the region has fallen slowly but steadily in recent years, but the major part of the shipment is likely to remain above 50 per cent for some years to some. In the present estimate of available ores about 50 per cent of metallic iron has been taken as the minimum. It is fully appreciated that ores below this grade are even now locally available and will soon be used in larger quantities, but such ores as a whole must be considered still as belonging to the future supply. The ore supply of the Lake Superior district available under present conditions is therefore taken to include all ore above 55 per cent iron, estimated at 2,500,000,000 tons, and 25 per cent of all ore containing between 45 and 55 per cent iron, giving a total of 3,500,000,000 tons exclusive of the Clinton ores.

ESTIMATES OF LOW-GRADE ORES.

Difficulties beset estimates of the tonnage of low-grade ores available for the future. The lower limit of such grade must be chosen somewhat arbitrarily, and when it is chosen there is lack of sufficient analyses of the iron formation as a whole to separate the tonnage above the given grade. The mixing of high-grade and low-grade ores also complicates the situation. Extensive drilling operations have been directed mainly to determine the percentage of ore above 50 per cent and little attention has been given to the grading of ores running below this percentage. The averages of all available analyses from portions of the formation outside of the ore at present available, made by the mining companies of the Lake Superior district, give the following results:

Character of the iron-bearing formations of the Lake Superior district.

DIAMOND-DRILL CORES.

State.	Holes.	Average iron content.	Analyses.	Total footage.
		Per cent.		
Michigan	77	36.52	3,897	22,202
Minnesota	24	38.00	1,094	5,400
Wisconsin	30	36.40	1,517	4,814

OTHER SOURCES.

Michigan:				
Trenches	....	41.53	94	975
Levels	....	38.40	905	[a] 7,500

[a] Approximate.

It seems entirely probable, in view of the fact that 40 per cent ore is even now locally in demand, that the depletion of the higher-grade reserves may in time require the use of 35 per cent ore. If so, the tonnage is enormous. Planimeter measurements of areas of the iron formation, multiplied by the depths quite within the limits of actual mining at the present time, give the following results:

Tonnage of iron formations.

District.	Area.	Depth.	Volume.	Quantity.
Michigan:	*Sq. miles.*	*Feet.*	*Cu. miles.*	*Tons.*
Crystal Falls	7.80	1,250	1.950	19,500,000,000
Marquette	28.50	1,250	7.100	71,000,000,000
Menominee	5.60	1,250	1.400	14,000,000,000
Penokee	11.60	1,250	2,900	29,000,000,000
Swanzy	1.00	1,000	.200	2,000,000,000
Minnesota:				
Mesabi	127.00	400	10.000	100,000,000,000
Vermilion	15.60	1,250	3.900	39,000,000,000
Wisconsin:				
Florence	.70	1,250	.175	1,750,000,000
	197.80	....	27.625	276,250,000,000
Ontario, Canada:				
Animikie	10.80	100	.20	2,000,000,000
Michipicoten	6.64	1,250	1.66	16,600,000,000
Other districts on north shore of Lake Superior	30.00	1,250	7.50	75,000,000,000
	47.44	....	9.36	93,600,000,000
Total	245.24	....	36.985	369,850,000,000

It is not proved, however, that this enormous tonnage will average as high in iron as these figures from the mining companies would indicate. Indeed, many parts of the formations are known to run lower than this. It is regarded safer, therefore, to use a smaller figure for the tonnage of ore running 35 per cent and over. Just what fraction of the total tonnage of the iron formations should be taken is a matter of more or less arbitrary choice. It is here put at 72,000,000,000 tons, divided as shown in the following table:

Estimates of Lake Superior ores.

District.	Available.	Not available.
Michigan:	*Long tons.*	*Long tons.*
Marquette district	110,000,000	15,900,000,000
Gogebic district	95,000,000	3,900,000,000
Menominee, Crystal Falls, and other districts	80,000,000	7,360,000,000
Minnesota:		
Mesabi district	3,100,000,000	39,000,000,000
Vermilion district	60,000,000	1,005,000,000
Cayuna and other districts	15,000,000	310,000,000
Wisconsin	40,000,000	4,525,000,000
Total	3,500,000,000	72,000,000,000

(2) ADIRONDACK ORES.[a]

GEOLOGIC RELATIONS.

The area of crystalline rocks forming the Adirondack district occupies the greater part of the State of New York north of the Mohawk Valley. The district contains a variety of iron ores differing in their character and geologic surroundings. Those found in sufficient abundance to be commercially important are nontitaniferous

[a] Based on reports of the New York State Survey.

magnetites, titaniferous magnetites, and red hematites. Some deposits of limonite also occur as bog ores, but they are not generally of sufficient size to be considered an available source of ore at the present time.

The rocks of the Adirondack district, with the exception of small patches of Paleozoic sediments, are entirely pre-Cambrian, and are either wholly crystalline or highly metamorphosed. They are provisionally classed in three groups: (1) Sedimentary rocks, marble, schist, and gneiss; (2) gneisses of undetermined origin, but probably in part, at least, sedimentary; and (3) igneous plutonic rocks, anorthosite, gabbro, syenite, and granite. The first group occupies a relatively small part of the area, but with its various members are associated all of the hematite deposits and many of the nontitaniferous magnetites.

NONTITANIFEROUS MAGNETITES.

These are the most widespread of the Adirondack deposits, but the more important ones occur in two groups on the eastern border of the district in the Lake Champlain basin and in the western part of the district in St. Lawrence County. In the first group are the well-known Hammondville, Mineville, and Lyon Mountain deposits, and in the second the Benson, Jayville, Fine, and Clinton deposits.

The ores show great variation in their mineral and chemical composition, ranging from lean varieties, which consist of magnetite intermixed with the constituents of the wall rock, to those made up of practically pure magnetite. The richest, obtained principally from the Mineville group, average from 60 to 65 per cent iron, and considerable quantities have been obtained which approached the theoretical iron content of magnetite (72.4 per cent). The deposits carrying less than 50 per cent iron are generally considered too refractory for direct smelting and their utilization depends upon concentration. Large bodies of such ore occur in the Lyon Mountain, Arnold Hill, and St. Lawrence County deposits. The lowest grade of ore now worked carries about 35 per cent iron ore before concentration.

Both Bessemer and non-Bessemer ores occur, in some cases in adjoining deposits, though generally the ores from all deposits of a group show a fair degree of uniformity in respect to phosphorus content. The leaner ores are apt to be lowest in phosphorus, and concentrates produced at Lyon Mountain contain less than 0.01 per cent of that element with 65 per cent iron. The ores also carry a variable proportion of sulphur due to the admixture of pyrite and more rarely pyrrhotite.

The deposits occur in a variety of forms such as are common to the magnetites found in gneisses and schists elsewhere. In general they have a lenticular bedded form and are parallel to the foliation of the inclosing rocks. They partake of the same structural folds and faults as these rocks, and must therefore have been deposited before the regional compression occurred to which these structural features are due. While there has been much diversity of opinion regarding the origin of these ores, the view generally held at present is that they were introduced by processes connected with the intrusion of the igneous rocks.

The Adirondack magnetites were mined as early as the latter part of the eighteenth century and supplied many bloomeries and forges and, later, small charcoal furnaces. These have now all disappeared, and the ores are mostly shipped to the iron-making centers for smelting. There are, however, two coke furnaces in the region that are supplied by local mines. The total production up to the present time has been somewhat over 36,000,000 tons. Both open-cut and underground mining methods are employed, but chiefly the latter because of the high inclination of the ore bodies. A depth of 1,500 feet has been reached in the workings at Lyon Mountain, and about 2,000 feet at Barton Hill. Practically all of the ore is concentrated by the magnetic process, which yields concentrates containing from 60 to 65 per cent iron and at the same time effects a partial elimination of the phosphorus and sulphur. In fact, the treatment of the richer ores is designed primarily to reduce the phosphorus, and the concentration is a subordinate object.

While a few of these deposits have been drilled with sufficient thoroughness to permit a fairly definite estimate of their contents, this is not generally the case, and in most cases even the extent of the outcrop is not accurately known. Lines of magnetic attraction indicate the presence of ore bodies concerning which little else is known, and finally large areas in the Adirondack Mountains, heavily forested and drift covered, have not been examined in sufficient detail to determine whether or not they contain iron-ore deposits. For these reasons it is impossible accurately to determine the ore reserves. It is estimated that the known deposits of high-grade ore will yield 35,000,000 tons, and that the leaner deposits, carrying over 35 per cent iron, will yield 75,000,000 tons of concentrates. The estimate of ore which is not now available because of great depth, or low grade, but which may be used eventually, is even more uncertain, but may be placed conservatively at 25,000,000 tons.

TITANIFEROUS MAGNETITES.

Under this class are included the ores which carry titanium as an essential ingredient. In general it amounts to at least 8 per cent of titanic acid (TiO_2), while the average is perhaps 15 per cent. These deposits occur within the margins of the gabbro-anorthosite area, chiefly in Essex and Franklin counties. In their relations to the inclosing rocks these deposits are sharply differentiated from the nontitaniferous magnetites which occur in the sedimentary and eruptive gneisses and schists. The titaniferous ores are believed to be the product of magmatic segregation, and hence intimately connected in origin with associated igneous rocks. The form of the ore bodies has not been accurately determined except in the case of a few of the smaller ones. The large bodies have nowhere been uncovered or sufficiently explored to afford an idea of their precise outlines. The richest ores contain little else than magnetite and ilmenite, and yield fully 60 per cent iron. From such pure aggregates there may be traced a continuous series of gradations by the entering of gangue minerals in increasingly greater proportion to the limiting wall rocks which hold only subordinate amounts of magnetite and ilmenite. The two minerals are often distinct in their crystallization, and show no tendency toward mutual intergrowth.

The use of ores containing high percentages of titanium is generally regarded as impracticable under present furnace practice because of the infusibility of the slags. They have, however, been smelted on a small scale in the Adirondacks, as well as in England and Sweden, and experiments have shown the feasibility of securing a fusible slag by properly proportioning the fluxes. A more promising solution of the problem is found in a reduction of the amount of titanium entering the furnace, both by concentration and by employing these ores as mixtures with nontitaniferous ores. Since the ilmenite is only feebly magnetic, it has been found practicable, at least on an experimental scale, to reduce the titanic oxide from 15 to 8 or 9 per cent by moderately fine-crushing and magnetic concentration.

These deposits have been explored only far enough to prove that they contain a very large amount of ore which simply awaits the development of methods for overcoming the metallurgical difficulties due to the presence of the titanium. Assuming that these difficulties will be overcome, it is estimated that the known deposits in the Lake Sanford district alone contain at least 90,000,000 tons sufficiently accessible and high in grade to be now available, and that they may contain in addition 100,000,000 tons, which are not now but will be eventually available as an ore supply.

RED HEMATITES.

Hematite deposits of workable dimensions occur on the northwestern side of the Adirondacks in Jefferson and St. Lawrence counties. They are associated with the folded pre-Cambrian sedimentary (Grenville) series of schists, limestones, and gneisses, which attain greater areal development in that section than elsewhere in the Adirondack region. The ores are mainly soft red hematites, with subordinate specular ore, and occupy zones of replacement along the contact of crystalline limestone and schist, and at times in the schist itself, with often a capping of Potsdam sandstone. A peculiar feature is the presence of a greenish mineral—locally called serpentine, but of chloritic nature—which seems to be an alteration product formed by reaction of the iron-bearing solutions upon the feldspathic schists and the occasional granitic intrusions of the walls. The source of the iron may be traced with some certainty to bands of pyrite and magnetite, which abound in the schists and which are subject to rapid weathering and to solution by ground waters. The principal mines have been opened along a narrow belt extending northeast from Antwerp nearly to the village of Gouverneur, but there are a number of outlying deposits that have been worked in former days for the supply of local furnaces. Mining was begun about 1835. Altogether the district has furnished probably 2,500,000 tons of non-Bessemer ore ranging from 45 to 60 per cent iron. The largest mines are the Dickson and Old Sterling near Antwerp and the Caledonia and Spragueville. Of recent years the output has been shipped to New Jersey and Pennsylvania for reduction.

Aside from the actual mine workings the district is practically unexplored, and it is impossible to draw any accurate conclusions as to the quantity of ore that may exist. Judging from the ore bodies developed in the mines recently operative, it seems safe, however, to place the resources at present available at 2,000,000 tons, while an equal quantity may be represented by other deposits that are not now workable by reason of their inaccessibility or other unfavorable circumstances.

Estimates of Adirondack ores.

	Available.	Not available.
Nontitaniferous magnetites:	*Long tons.*	*Long tons.*
High-grade ores	35,000,000	....
Concentrating ores (concentrates)	75,000,000	25,000,000
Titaniferous magnetites	90,000,000	100,000,000
Red hematites	2,000,000	2,000,000

(3) CLINTON ORES.

CHARACTER OF THE ORE.

The Clinton iron ore, so named from its typical occurrence at Clinton, N. Y., is an amorphous red hematite mixed with calcium carbonate, silica, aluminum silicate, and other minerals in minor quantities. It includes the varieties known as fossil ore and oolitic ore.

It occurs in lenticular beds analogous to the strata of sandstone, shale, and limestone, with which they are interbedded.

The fossil ore consists of aggregates of fossil organic remains in which the original calcium carbonate has been replaced partly or wholly by ferric oxide. The fossils, which consist of broken and waterworn fragments, were evidently gathered into beds by the action of waves and currents, and subsequently cemented together by calcium carbonate and ferric oxide. More or less clay material was also included in the beds during their deposition, and this now forms thin seams of shale.

The oolitic ore consists of aggregates of flat grains with rounded edges about the size and shape of flaxseeds. These grains generally lie parallel to the bedding planes of the rock, and the mass is cemented by ferric oxide and more or less calcium carbonate. The flattened grains have a nucleus of quartz, generally very minute, about which successive layers of iron oxide, and, in many instances, thin layers of amorphous silica and aluminous material, have been deposited. One of the two varieties of ore generally predominates in a bed, but in certain localities both fossil and oolitic materials are mixed in nearly equal proportions. The fossil ore, where unweathered, as compared with the oolitic ore in the same condition, is apt to be the more calcareous, while the oolitic ore may carry higher proportions of silica and alumina.

A characteristic of the Clinton ore is that where it has been weathered or acted upon by surface waters the lime carbonate is dissolved out, thereby increasing the content of iron oxide, silica, and other constituents proportionately. Such altered ore is termed " soft ore," and it is usually porous and friable as compared with the unaltered material, which is termed " hard ore." The alteration of the ore beds takes place at the outcrop and extends to depths varying from a few inches to 400 feet, depending on the attitude of the beds and on the thickness and permeability of the overlying rocks. The quantity of the soft ore is relatively small in comparison with the hard ore, and owing to its higher content of iron and its greater accessibility, a large part of the soft ore has already been mined.

In general the hard and semihard ores range in percentages of major constituents as follows: Metallic iron, 30 to 45 per cent; lime, 5 to 20 per cent; silica, 2 to 25 per cent; alumina, 2 to 5 per cent; magnesia, 1 to 3 per cent; phosphorus, 0.25 to 1.5 per cent; sulphur, a trace to 0.5 per cent; and water, 0.5 to 3 per cent. The ore is therefore of non-Bessemer grade. Small quantities of manganese are found in the Clinton ore in places, especially in the South. The content of this mineral seldom exceeds 0.25 per cent. In the soft ore the lime generally runs less than 1 per cent, so that the percentages of the other constituents are proportionately higher.

GEOLOGIC RELATIONS AND DISTRIBUTION.

The Clinton formation, of which the Clinton ore beds are a part, consists of lenticular, overlapping sedimentary beds, chiefly shale, sandstone, and limestone. In some places shale predominates, in others sandstone, and less commonly limestone. One or more iron-ore beds are generally present, although over large areas none occur.

The formation has a wide distribution in the eastern half of the United States. In the Mississippi Valley it is present in Wisconsin and Missouri, in the latter State having been recognized in a drill hole by the presence of a bed of iron ore over 8 feet thick at a depth of 2,000 feet. In eastern Wisconsin the formation is represented by a bed of iron ore only, which varies in thickness from 1.5 to 25 feet. In Ohio, Indiana, and northeastern Kentucky the formation occurs generally with thicknesses of 35 to 50 feet, but containing ore only in the latter State. In northern New York the Clinton rocks extend in a east-west strip from Niagara River to Otsego County. Here the thickness ranges from 32 to 295 feet. In all these States the beds are approximately horizontal or dip at very low angles. In the Appalachian belt from northern Pennsylvania southwestward to central Alabama the Clinton is a well-developed formation, and the beds are generally inclined at angles of 10° to 90°. Its thickness decreases from 2,000 feet in Pennsylvania to about 850 feet in Virginia, 300 to 750 feet in Tennessee, and 200 to 700 feet in Alabama and Georgia.

DISTRIBUTION.

While the total length of outcrop of all the areas of ore-bearing Clinton formation would reach several thousand miles, only a relatively small part of this outcrop contains ore workable under present conditions. The workability of an ore bed depends on its thickness, extent, composition, and attitude, and also upon its situation with respect to transportation routes, fuel, and markets. The first set of factors are of greatest importance, since few areas of good ore are so inaccessible that they will not sooner or later be reached by railroad. Local conditions also play an important part in determining the workability of an ore bed. For instance, in districts where several such beds occur in the formation, as in Alabama, only the thicker and richer ores are now worked, while others that would be at once exploited if they were in Pennsylvania are for the present neglected.

Wisconsin.—In Wisconsin Clinton ore has been produced in Dodge County since 1849. The ore occurs at Iron Ridge in an irregular lens-shaped bed between the "Cincinnati shale" and the Niagaran limestone. Its thickness varies from 1.5 to 25 feet. At other points, within a radius of 10 miles, the same ore bed occurs and it is known to thin out to the east. Toward the west the ore has been eroded, so that the outcrop lies in a westward-facing scarp about 60 feet high, capped by Niagaran limestone. Open-cut and underground mining have been carried on here. The ore as originally mined ran low in lime and contained about 45 per cent iron. It was partially hydrated and represented the "soft ore" of the outcrop. In 1906 the production of ore from Iron Ridge was nearly 90,000 tons, and in 1907 about 22,000 tons. Recent exploration work has proved that a considerable reserve of hard ore remains in this district, amounting to about 40,000,000 tons.

Kentucky.—A bed of Clinton ore, averaging probably more than 2 feet in thickness, occurs in Bath County, Ky., underlying an area of about 8 square miles. This ore lies nearly horizontal, but most of it is below too heavy cover to admit of mining under present conditions. It carries from 30 to 40 per cent iron and 13 to 16 per cent lime carbonate. At present the ore is mined by stripping where the cover is not more than 8 to 10 feet thick. The deposit has produced approximately 190,000 tons, and it is estimated that there are remaining 25,000,000 tons, one-tenth of which may be available under present conditions.

New York.—The belt of ore-bearing Clinton within New York State extends from Rochester on the west nearly to Utica on the east, a distance of about 130 miles. The width of outcrop of the formation reaches a maximum of 5 miles. The beds dip toward the south, from 45 to 80 feet to the mile. Conditions are extremely favorable for underground mining and should permit work to a distance of 3 to 5 miles from the outcrop wherever the ore is of sufficient thickness. The ore bed that is worked varies in thickness from 1.5 to 4 feet, with an average of about 2.5 feet. It carries 35 to 45 per cent of iron, with an average, where worked, of about 40 per cent. The phosphorus is high, from 0.25 to more than 1 per cent, and the sulphur, while variable, runs from traces up to 0.5 per cent. The ore has been worked in Wayne, Cayuga, and Oneida counties.

An estimate made by the New York State Survey of the tonnage contained in this district, mainly in these three counties, gives a total of 600,000,000 tons. Ore beds less than 1.5 feet thick and at a depth of more than 500 feet, as well as those carrying less than the average content of iron, have been excluded from consideration. Much of this ore, however, is not available under present conditions.

Pennsylvania.—The length of outcrop of the Clinton formation in Pennsylvania is very great owing to its repetition in the many anticlinal folds within the central part of the State. In the counties of Snyder, Mifflin, Juniata, Blair, Huntingdon, and Bedford, three or four thin beds of red ore occur, ranging in thickness from a few inches to more than 2 feet. The ore on the outcrop is usually soft and rich enough to work by stripping, but the hard ore under cover is in most places too thin to be worked at present. In a few places, however, where the beds are from 1 to 2 feet thick, underground drifts and slopes have been driven for short distances in the hard ore.

The soft ore carries 40 to 50 per cent of iron and from a trace to 5 or 6 per cent of lime. The hard ore carries 20 to 35 per cent of iron, and in places as much as 25 per cent of lime.

Less than 20,000 tons a year of Clinton ore are now being produced in Pennsylvania, and it is probable that the reserves of this ore at present available in the State are not much in excess of 5,000,000 tons.

Virginia and north Tennessee.—The ore beds in the Clinton in Virginia are generally too thin to be considered important reserves after the soft ore shall have been mined out. In the west-central part of the State beds at Lowmoor range in thickness from 16 to 21 inches, and at Iron Gate from 8 to 12 inches. The soft ore carries 46 to 57 per cent of iron. Nearly 90,000 tons were shipped in 1907 from mines in this district, and at this rate of production most of the easily accessible soft ore will probably be exhausted within ten or twelve years.

The Clinton formation, outcropping along the foot of Cumberland Mountain, is ore bearing from Cumberland Gap, Va., to La Follette, Tenn. Near Cumberland Gap there are three ore beds ranging in thickness from 6 inches to 2.5 feet. Only the upper bed, the thickness of which ranges from 15 to 20 inches, is workable. Southwestward toward La Follette the ore increases in thickness to 3.5 feet. Here practically all the soft ore has been mined out, so that only a hard ore, carrying 26 to 32 per cent of iron, remains. It is estimated that about 16,000,000 tons of such ore are still available in the Cumberland Gap-La Follette district.

It is possible that future exploration of the extensive areas of Clinton formation within Virginia and West Virginia may reveal additional ore reserves.

Rockwood-Chattanooga-Gadsden district.—This district embraces an area about 30 by 125 miles in the Appalachian valley region of east Tennessee, northwest Georgia, and northeast Alabama. Steeply dipping Clinton strata outcrop in narrow strips on both sides of Walden Ridge and Lookout Mountain and in the Whiteoak Ridge and other synclines of the Tennessee Valley. Ore is mined at North Chattanooga, Rockwood, Cardiff, Euchee, Welker, and Ooltewah, Tenn., and has been mined extensively at Inman. The important mining localities in Georgia are at Rising Fawn and Estelle, and in Alabama at Battelle, Portersville, Crudup, Attalla, and Gadsden.

The workable ore beds range from 2 to 5 feet in thickness and carry from 30 to 40 per cent of iron, 10 to 25 per cent of lime, and 0.5 to 0.7 per cent phosphorus. The use of much of the ore that is low in iron and high in lime depends upon the continuance of supplies of brown ore. The latter is mixed in the blast furnace with red ore that contains more than sufficient lime to be self-fluxing.

Estimates based upon fairly complete examinations place the available Clinton ore of the Rockwood-Chattanooga-Gadsden district at 86,570,000 tons, and the ore that will ultimately become available at 440,000,000 tons.

Birmingham district.—The Birmingham district includes the Clinton ore-bearing areas of Alabama from Springville southwest beyond Woodstock. As in Tennessee and Georgia, the Clinton formation in Alabama outcrops in narrow strips on the flanks of synclinal mountains. The dips range from 10° or 15° to vertical. The most important outcrop is along the crest of Red Mountain for about 25 miles near Birmingham. Other areas of minor importance occur along West Red Mountain near Birmingham. The thickness of the more important ore beds ranges from 2.5 to 12 feet. The ore carries from 30 to 40 per cent of iron, 10 to 25 per cent of lime, 0.3 to 0.6 per cent phosphorus, and from a trace to 0.1 per cent sulphur.

Estimates of tonnage of available ore for the Birmingham Clinton ore field indicate a supply of probably 358,470,000 tons, and of ore not at present available of about 438,000,000 tons.

SUMMARY AND ESTIMATES.

The Clinton formation has a wide distribution in the central and eastern portion of the United States, but contains commercially important ore beds in only a part of its area. The most important deposits are in the Birmingham, Chattanooga, and New York State districts, while less extensive deposits occur in Virginia, Wisconsin, Pennsylvania, and Kentucky.

It is evident from the above description that the quantity of ore contained in any area of the Clinton formation may be calculated with a fair degree of accuracy, provided sufficient data are available as to its dip and as to variations in thickness and quality of the ore beds. An assumption must be made as to depth-limiting workability under a variety of structural conditions, and since this is a matter of opinion it will vary somewhat widely and introduce corresponding differences in the results. Conditions of blast-furnace practice locally may define the quality of a workable ore. In places where brown ores are available for mixing with Clinton ores, an ore of the latter class can be used as a flux, although it runs so low in iron and so high in lime that alone it would not be acceptable. The estimates of available ores made by various experts do not, however, differ materially. In case of the total ore which is not now available, but which may be mined eventually, the variance in estimates is much greater, since more unknown factors enter into the problem.

The estimates given below are based upon detailed examinations of the more important districts by the United States Geological Survey for the Birmingham and Chattanooga districts, and by the State Survey for the New York district, with a study of all obtainable drill records.

Estimates of Clinton ores.

District.	Available.	Not available.
	Long tons.	*Long tons.*
Birmingham	358,470,000	438,000,000
Chattanooga	86,570,000	440,000,000
New York	30,000,000	570,000,000
Virginia-North Tennessee	16,000,000	50,000,000
Wisconsin	10,000,000	30,000,000
Pennsylvania	5,000,000	50,000,000
Kentucky-West Virginia	2,500,000	42,500,000

(4) APPALACHIAN METAMORPHIC ORES.

This group includes the deposits of magnetite and specular hematite associated with the crystalline and metamorphic rocks of the Piedmont and Appalachian mountain belts, which extend from southern New York to central Alabama. The ore deposits are not uniformly distributed throughout this area, but are confined to certain portions where geologic conditions have been favorable for their accumulation. The most important districts are (1) the highlands of southern New York and northern New Jersey; (2) the James River district, Virginia; (3) the Cranberry district, North Carolina; (4) the Piedmont district, North Carolina; (5) the Yorkville district, South Carolina; (6) the Talladega gray ore district, Alabama. The last-named district is included in this group for convenience, although it differs materially in its geologic relations from the others.

The ore deposits of this group have the form of lenticular beds or elongated pods, which are interlaminated with the gneisses, schists, or crystalline limestones. The individual deposits vary in thickness from a fraction of an inch up to 50 or even 80 feet, but the majority of the workable deposits are from 4 to 15 feet thick and are apt to show rapid variations by pinching and swelling on both the strike and the dip. They vary in composition from practically pure iron ore to a material containing a large proportion of gangue minerals. In general, the larger deposits contain the smaller proportion of iron and can be worked only by the employment of some method of concentration.

The deposits rarely occur singly, but are more often disposed in rather narrow belts separated by wider belts of barren gneiss and schist. Since the ores were undoubtedly derived from a deep-seated source, there is no reason to anticipate a failure in depth, although pinches and swells are to be expected in the course of deep mining, and the cost of mining will necessarily increase with depth.

The gray hematites of the Talladega district and certain hematite deposits of Virginia and Georgia are here included for convenience, though they occur under entirely different geologic conditions from those above described. These hematites have the appearance of regularly bedded deposits, associated with sedimentary rocks which have suffered only slight metamorphism. Whether or not they were deposited at the same time as the inclosing sediments has not been definitely determined. They possess much greater uniformity, both on the dip and along the strike, than the magnetites in the crystalline rocks, and for practical purposes may be regarded as original bedded deposits.

In view of the irregularities in thickness of the magnetite beds, which can not be determined in advance of thorough prospecting, it is impossible to make any accurate calculation of the amount of ore which they contain even when their area at the surface is known, and this is rarely the case. The following estimates, therefore, are only approximate, particularly the amount assigned to the nonavailable class:

Estimates of Appalachian metamorphic ores.

Ores.	Available.	Not available.
	Long tons.	*Long tons.*
Magnetites, including some titaniferous magnetites and some hematite	47,500,000	74,500,000
Specular hematites, including some limonites	8,000,000	53,000,000

(5) APPALACHIAN BROWN ORES.

GEOLOGIC RELATIONS.

This group embraces those deposits of brown ores associated with the Appalachian belt of closely folded sedimentary rocks which extends continuously from northern Vermont southwestward to central Alabama. It is bounded on the east by the older crystalline and metamorphic rocks of the Appalachian Mountains, and on the west by the younger "Coal Measures." It is underlain by limestones, dolomites, shales, sandstones, and quartzites, ranging in age from Cambrian to Carboniferous. The beds, originally deposited in approximately horizontal layers, have been folded and faulted so that they now occupy all possible attitudes. This has given rise to conditions favorable to the rapid weathering of the rocks. The steeply dipping sandstones and quartzites form sharp ridges, while the more easily eroded limestones, dolomites, and shales form the intervening valleys, their surfaces being generally covered with a deep mantle of residual materials. These rocks, particularly the shales and some of the limestones, contain small quantities of iron minerals, sulphides, carbonates, and silicates, and in the process of weathering and erosion, by which many thousand feet of strata have been removed, the iron originally contained in these widely disseminated minerals has been concentrated, where conditions were favorable, as the hydrated oxide forming the deposits of brown ore. These deposits, while presenting great diversity in form, fall into three classes, known as mountain ores, valley or limestone ores, and Oriskany ores.

MOUNTAIN ORES.

These deposits are so called because they always occur upon the flanks or at the base of a sandstone, chert, or quartzite ridge, and throughout Virginia, Tennessee, Georgia, and Alabama they are most extensively developed along the extreme eastern margin of the valley belt where the Cambrian quartzite forms a high ridge flanking the crystalline rocks. The quartzite beds dip steeply beneath the overlying shales and limestones, and iron derived from the latter during the process of weathering has been concentrated downward upon this impermeable foot wall. Similar conditions favorable for ore concentration occur elsewhere in the Appalachian belt where the Cambrian quartzite in isolated ridges dips beneath the overlying shales, as at Anniston, Ala., and also at a few points where the lower Carboniferous chert has formed an impermeable foot wall, as at Sugar Valley, Ga. The deposits present great diversity in form, varying from fissure veins and replacement zones in the sandstone and shale, through blanket deposits resting on the quartzite, to irregular pockets scattered through the residual clay. The last are the most abundant and characteristic. Their size can rarely be determined in advance of development, even by systematic prospecting, and estimates of their available tonnage vary between wide limits.

VALLEY OR LIMESTONE ORES.

These are associated with the great limestone and dolomite formations which underlie much of the Appalachian belt. They also are derived from the iron minerals originally disseminated through the rocks and have been concentrated during the process of weathering and erosion. Their location depends on the original abundance of these minerals in the rocks and on favorable conditions for concentration afforded during erosion, in some cases probably by the fracturing of the beds and the consequent free underground circulation of water, and in others by the location of an easily soluble bed of limestone toward which drainage from surrounding areas brought the iron and deposited it as bog ore. They are always embedded in the residual mantle composed of the insoluble portions of the underlying rocks. The deposits vary in form, but generally consist of concretionary masses ranging in size from those containing several tons down to pellets the size of a pea, disseminated through the residual clay.

ORISKANY ORES.

These deposits are more regular in their occurrence, being limited to a definite horizon in the Helderberg limestone immediately beneath the Oriskany sandstone. They are confined to a comparatively small portion of the valley belt, chiefly in southwestern Virginia with a few deposits in Pennsylvania and West Virginia. The iron was originally disseminated in the overlying shales, and wherever these shales occurred in sufficient thickness and the limestone bed occupied a favorable attitude its lime carbonate has been replaced by the iron oxide for a greater or less distance below the surface. The deposits frequently extend continuously for several miles along the outcrop, being made up of a series of lenses which may reach 75 feet in their thickest portions and thin down to a foot or less where adjacent lenses come together. The greatest depth to which the ore has been found is about 600 feet. Where the replacement has been complete and extensive, therefore, it has the form of a bedded deposit and the ore content can be estimated with some certainty. The deposits consist either of fairly solid ore or of irregular masses and seams of ore embedded in clay.

DEVELOPMENT AND ESTIMATES.

The Oriskany deposits are mined both by stripping on the outcrop and by regular underground mining. The mountain and valley ores are nearly always mined in open pits, in the larger operations by steam shovel, and in a few cases by the hydraulic method. Where hand mining is done, a part of the ore is sent direct to the furnace without other treatment than hand picking, but where the steam shovel is used everything is passed through the washer. In most cases sorting tables and jigs are employed in addition to the washer. By these means the associated materials, consisting of clay, chert, and other rock fragments, are removed from the ore. The average iron content of the ore as shipped is about 45 per cent, and the phosphorus is generally above the Bessemer limit. The deposits of this group, being widely disseminated and easily mined in open pits, furnished a large part of the ores used by the small charcoal furnaces in the early development of the iron industry in the United States. With increase in capacity of furnaces a more reliable ore supply has been sought, and many districts which were formerly heavy producers have been temporarily abandoned. The ore is still in demand, however, chiefly for mixture with the calcareous Clinton ores, and its production will doubtless increase in the future beyond any point previously reached.

From the above description of these brown-ore deposits it will be readily understood that extreme difficulty must attend any attempt to estimate their total tonnage. It is unsafe to base an estimate on the number of known occurrences of the ore multiplied by an average content derived from the known yield of certain deposits which have been worked out, for the best deposits are the ones most apt to be exploited first. The estimates given below are based in part on systematic examination and measurement of all known deposits in certain districts and in part on general considerations of distribution and geologic occurrence. The amounts given in the second column of the table, representing ore not now available, are confessedly little better than guesses and future exploration may show them to be much too low. It should be stated further that estimates made by competent experts differ from the figures here given by a factor varying from 0.7 to 3.

Estimates of Appalachian brown ores.

	Available.	Not available.
	Long tons.	*Long tons.*
New England and New York	1,000,000	1,500,000
Pennsylvania, Maryland, and New Jersey	10,000,000	12,000,000
Virginia, West Virginia, and East Tennessee	35,150,000	136,000,000
Alabama, Georgia, and North Carolina	19,250,000	32,000,000

(6) APPALACHIAN CARBONATE ORES.

This group of deposits includes the beds of carbonate ores and their oxidized outcrops which occur in the Carboniferous rocks within a broad belt stretching from western Pennsylvania through Ohio into northeastern Kentucky, and probably extending also into Tennessee and Alabama. The rocks occupying this belt are chiefly sandstones and shales, with occasional thin beds of limestone. The beds are nearly horizontal, and the topography is such that the outcrop of any stratum is extremely sinuous and may have a length many times the shortest distance between two points. This combination of structure and topography has an important bearing on the possible utilization of the iron ore.

The group embraces several varieties of ore locally distinguished as limestone ore, block ore, kidney ore, and black-band ore, each of which is accompanied by a corresponding variety of oxidation product. All of the varieties are non-Bessemer ores. The limestone ores are associated with thin beds of limestone, the most widely distributed being the Vanport and Maxville. The ore beds lie immediately above the limestones, which they sometimes entirely replace. They are usually only a few inches thick, but occasionally expand to several feet. For varying distances from the outcrop the original iron carbonate has been oxidized to a dense brown ore, with loss of carbonic acid and increase in proportion of iron. The unaltered carbonate contains 30 to 35 per cent iron, and the alteration product from 43 to 47 per cent.

The block ores are fairly regular bands of iron carbonate, interstratified with shale or fine sandstone. They are more persistent and uniform in thickness than the other varieties. In Kentucky three persistent beds are recognized, having a total outcrop of over 450 miles. The quality of the ore varies inversely with the thickness of the beds, the thinnest beds carrying the best ore. The unaltered carbonate carries from 29 to 34 per cent iron, and the brown ore on the outcrop from 33 to 43 per cent.

The kidney ores, as their name implies, are concretionary in form and occur in certain beds of clay shale, rarely forming continuous layers. They grade into the black-band ores, which are usually more or less closely associated with coal beds and contain carbonaceous matter which gives them a black color. These concretionary forms generally contain the purest iron carbonate and on oxidation at their outcrop yield a correspondingly pure limonite, or brown ore.

In the early history of iron making in the United States this ore belt in Pennsylvania, Ohio, and Kentucky contained a large number of small charcoal furnaces and the aggregate amount of ore produced was very considerable. With the disappearance of the forests the iron industry in this region declined, and the use of these ores has practically ceased. The production was confined largely to the oxidized surface ores, which not only were more easily accessible but gave the best results in the primitive furnaces. While the deposits of this group contain a large aggregate tonnage, practically all of it must be classed as not at present available. The principal reason that the ore can not now be worked at a profit is the fact that the nature of the deposits does not permit operations on a large scale. At only a few points are the beds sufficiently thick and persistent for underground mining, and stripping is therefore the method used. The distance which stripping can be carried into the hillside depends on the slope and the thickness of the bed. An average width of the belt from which the ore can be mined has been assumed as 100 feet, and the average thickness of the ore bed from 10 to 12 inches. The aggregate length of outcrop of the several ore beds has been taken as follows: For Pennsylvania, 866 miles; Ohio, 2,056 miles; and Kentucky, 1,260 miles. With these assumptions the total tonnage of carbonate and associated limonite ores which may ultimately be produced in these three States, and in Tennessee and Alabama, is as follows:

Estimates of Appalachian carbonate ores.

	Available.	Not available.
	Long tons.	*Long tons.*
Pennsylvania		46,000,000
Ohio		200,000,000
Kentucky		60,000,000
Tennessee-Alabama		2,000,000

(7) WEST TENNESSEE BROWN ORES.

This group embraces the ore deposits within a broad belt extending from the northern border of Alabama and Mississippi across western Tennessee and Kentucky. This region is a plateau of moderate elevation which has been dissected by the Tennessee River and its tributaries. The rocks underlying the ore-bearing territory are lower Carboniferous cherty limestones. The ore deposits closely resemble the limestone ores of the Appalachian Valley. They vary in size from scattered concretions embedded in surface cherty clay to bodies having a depth of 120 feet or more and containing upward of half a million tons. The larger deposits are confined to slight depressions in the plateau surface, in which deposits of waterworn bowlders suggest the former presence of streams. The ore was doubtless derived from the accumulation during the process of weathering and erosion of iron contained in minerals disseminated through the higher formations. These ores have been mined for many years, supplying a number of local charcoal furnaces and being shipped for mixture with the calcareous Clinton ores of the Chattanooga and Birmingham districts.

In the absence of detailed examination of this ore belt, estimates of ore tonnage contained in these deposits must rest upon a very small foundation of ascertained fact. A few of the deposits have been studied, as those at Russellville, Mannie, and Goodrich, and the estimates for the entire district are based upon these disconnected observations. These estimates place the available ore at 10,000,000 tons, and the ore not now available, chiefly because of the excessive cost of transportation and of working scattered deposits, at 15,000,000 tons.

(8) EAST TEXAS BROWN ORES.

This group of deposits occurs in the northeastern portion of Texas and the adjacent portions of Louisiana and Arkansas. They differ materially in their geologic relations and in the problems of utilization from the brown ores previously described. The region is underlain by Tertiary formations, chiefly unconsolidated sands, clays, and greensands. The ore forms a fairly uniform layer, rarely averaging over 2 feet in thickness, and covering large areas. It is at places exposed at the surface and is elsewhere covered by soil and sand to a depth of 6 feet or more. The ore averages about 46 per cent of iron, and is above the Bessemer limit in phosphorus. It is generally high in both silica and alumina. The deposits are probably derived from the oxidation in place of beds and nodules of iron carbonate, although it may be in part due to the concentration of iron derived from the greensand and other iron minerals disseminated through adjacent formations. While these deposits contain in the aggregate a large amount of ore of fairly good grade, its utilization presents somewhat serious difficulties. Owing to the thinness of the deposits the ore can not be excavated with steam shovel or other mechanical devices. The scarcity of water in the region will prevent hydraulicking and also economical washing of the ore, so that only the lump ore can be utilized.

These deposits have been mined at a number of points and have supplied a local furnace for some years. The same region is underlain by beds of lignite, one of which at a depth of about 50 feet has a thickness of over 4 feet. Should it prove practicable to use this lignite in blast-furnace practice, directly or as a gas producer, its occurrence in the immediate vicinity of the ores would prove highly advantageous in their utilization.

In the absence of detailed surveys it is not possible to closely estimate the area of the workable deposits. The total area known to be underlain by the ore-bearing formation is about 500 square miles, and of this probably 50 square miles contain a bed averaging 2 feet in thickness, which is taken as the limit of profitable working at the present time. Upon this basis the district is estimated to contain 260,000,000 tons of available ore, and it is probable that it contains twice this amount of ore that is not now available but will be utilized eventually.

(9) OZARK ORES.[a]

GEOLOGIC RELATIONS.

The Ozark district embraces the southern half of Missouri and a narrow strip along the northern border of Arkansas. It consists of a broad, unsymmetrical, domelike uplift, by which the older rocks are brought to the surface near the center of the district and, dipping outward in all directions, pass under successively younger formations toward its circumference. The oldest rocks in the district are igneous, porphyry and granite, on the irregularly eroded surface of which the Cambrian formations were deposited. The greater part of the district is occupied by cherty, magnesian limestone, with subordinate sandstones and shales.

The district contains four classes of iron ores in deposits of sufficient size to be of commercial importance. These are (1) coarse specular hematite, occurring in veins in porphyry and in associated conglomerate beds; (2) fine specular hematite, occurring in pockets at the contact between Cambrian sandstones and limestones; (3) brown ore, limonite, occurring in pockets in the residual clay and chert derived from the weathering of limestones; and (4) red hematite, occurring as bedded deposits with Carboniferous shales and sandstones. In addition the "Coal Measures" contain occasional thin

[a] Based on reports of the Missouri State Survey.

beds of iron carbonate, but these are not known in deposits of commercial size. Each of these classes of ore being associated with certain geologic formations, their distribution is dependent on the structure of the district. The porphyry ores are confined to a small district in Iron County, practically to the two localities, Iron Mountain and Pilot Knob. The fine hematites are grouped within an area about 50 miles in diameter, chiefly in Phelps and Crawford counties, where the Roubidoux sandstone occupies the surface. The limonite deposits form two irregular groups, the first occupying the basin of the Osage River and the second extending along the southeastern margin of the district. The deposits of the red hematite are less numerous than the other kinds, and occur chiefly along the northern margin of the district.

SPECULAR PORPHYRY HEMATITE.

The interest in these deposits is chiefly historic, since they are now practically exhausted and thorough testing in the most favorable localities has entirely failed to reveal additional deposits. These were the first iron ores worked west of the Mississippi River and supplied several local furnaces, the first of which was built about 1815. They continued to produce up to 1893 and have had a total production of 4,500,000 tons. The history of the development and exhaustion of these deposits is instructive as illustrating the fallacy of the popular belief that many ore bodies are inexhaustible and showing that they are very definitely limited in the amount of ore which they will yield.

SPECULAR SANDSTONE HEMATITE.

These deposits consist of irregularly circular pockets from 300 to 500 feet in diameter, located in the sandstone and extending downward into the underlying limestone. The ore occurs both as bowlders mixed with fragments of sandstone, chert, and residual clay and as a solid, indistinctly bedded mass. The unaltered ore is a dense, fine-grained blue or gray hematite, which near the surface has been changed largely to soft red hematite or to limonite. The better grades contain 55 to 67 per cent of iron and are generally low in phosphorus. In addition there are large amounts of siliceous ore which are not available under present conditions. The yield of individual deposits may be in excess of half a million tons, and unless erosion has cut into deposits of this size they may afford little or no indication of their presence at the surface. In the absence of thorough testing, surface indications are therefore unreliable as a basis for estimates of the ore content of these deposits. A large amount of uncertainty must be present in any estimate of total tonnage, and the figures given are regarded only as roughly approximate. These deposits at present form the chief source of iron-ore production in the Ozark district.

BROWN ORES.

Deposits of this class occur in very large numbers as irregular pockets in the residual material overlying various limestone formations. They are due to the concentration of iron contained in minerals originally disseminated through the rocks which have been removed and were concentrated during the process of weathering and erosion. They are in part also derived from the solution and redeposition at lower levels of other iron ores, as the specular and red hematites. Over 500 localities are listed at which these deposits occur, and while they vary widely in the amount of ore contained, the aggregate tonnage must be very considerable. Owing to the small size of many of these deposits, their distances from transportation places them in the class of ores not at present available. Also, in a considerable proportion of the deposits, the ratio of ore to clay is too low for profitable working at present.

RED HEMATITE.

These ores occur as regularly bedded deposits in certain portions of the lower Carboniferous formations along the northern border of the Ozark district. They are variable in thickness and horizontal extent. The deposits are practically undeveloped, and owing to the low grade of the ore and the thinness and variability of the beds, they can not at present compete with other ores that are higher in grade and are more cheaply mined.

SUMMARY.

The estimates of tonnage contained in the various classes of ore deposits in the Ozark district are summarized in the following table:

Estimates of Ozark ores.

	Available.	Not available.
	Long tons.	*Long tons.*
Sandstone hematite	15,000,000	5,000,000
Brown ore	30,000,000	45,000,000
Red hematite	....	5,000,000

(10) ROCKY MOUNTAIN METAMORPHIC ORES.

This group embraces the deposits of magnetite and specular hematite associated with crystalline schists and gneisses at various localities in the Rocky Mountain region. They are similar in most particulars to the deposits of the same ores in the crystalline metamorphic belt of the Eastern States. They consist of lenticular beds conforming in dip and strike to the foliation of the inclosing rocks and varying greatly in thickness within short distances, both in depth and along the outcrop. Associated with these beds, and evidently derived from them, are occasionally found secondary fragmental deposits, which are sometimes overlain by later sedimentary or igneous formations.

The best-known deposits of this group occur in the Hartville district, Wyoming, and in the Llano district, Texas. They also occur at various points in Colorado, Nevada, New Mexico, and Arizona, and in general may be expected wherever there are considerable areas of crystalline gneisses and schists. They have been extensively worked in the Hartville district, supplying a part of the ore for the furnaces at Pueblo, Colo., and being used also to some extent for fluxing silver ores. It is probable that a much larger proportion of the deposits of this group are as yet undiscovered than of any other group of iron-ore deposits. In view of the extremely meager information, estimates of their contents have little value. The ore is generally high grade, though sometimes siliceous, but a large proportion of the deposits are not at present available by reason of remoteness from transportation lines and distance from suitable fuel for their reduction.

(11) IGNEOUS CONTACT ORES.

GEOLOGIC RELATIONS.

This group is based exclusively upon its geologic relations, and the deposits are widely distributed, though the most of them are located in the Rocky Mountain and Pacific States. The essential characteristics of the deposits are the following: They are steeply dipping, lens-shaped bodies, which closely follow the contact of an intrusive igneous mass and an intruded limestone. They occur partly within the igneous rock as dikelike veins and partly within the limestone, but generally at the immediate contact. The limestone is always altered for a variable distance, sometimes several hundred feet from the contact, the alteration consisting in extreme silicification and the development of lime-bearing metamorphic minerals. The ores are magnetite, or more generally an intimate mixture of magnetite and hematite. They are often altered at the surface to red hematite and to some extent to limonite. The original bedding planes of the limestone are sometimes preserved in the ore body. The gangue consists of quartz and aluminous silicates, in part the recrystallized impurities of the limestone and in part minerals introduced along with the iron. The ores are believed to be due to hot solutions rising from a deep-seated source through fissures in the igneous rock at a period closely following its complete or partial solidification.

CORNWALL DISTRICT, PENNSYLVANIA.

The principal eastern representative of this group is in eastern Pennsylvania, where the ore, chiefly magnetite, has been mined since the early part of the eighteenth century. These deposits, of which the Cornwall mine is considered the type, occur at the contact of intrusive masses of Mesozoic diabase and Cambrian limestone. The more easily accessible portions of the deposits have been mined out, but they are estimated to contain 50,000,000 tons of ore, of which about 15,000,000 tons are considered available under present conditions.

IRON SPRINGS DISTRICT, UTAH.

These are the best known of the western representatives of the group. They are located in southwestern Utah, about 250 miles from Salt Lake. The ore, which consists of both magnetite and specular hematite (70 per cent of the former and 30 per cent of the latter), occurs at or near the contact of laccolithic intrusions of andesite in Carboniferous limestone. The aggregate surface of the known ore bodies is 5,430,000 square feet, and the calculated tonnage to a depth of 130 feet is 40,000,000 tons. While this is the greatest depth at which the ore has been actually observed in prospect pits, a careful consideration of its geologic relations leads to the conclusion that it extends to considerably greater depths, and probably twice the above tonnage may be taken as the amount which is present but not now available. Practically no development has taken place except the sinking of a large number of prospect pits.

OTHER DISTRICTS.

Ore deposits belonging to this group are known to occur at numerous localities throughout the West, but they have not generally been examined in sufficient detail to permit accurate estimates of tonnage being made.

In Utah deposits occur at Bull Valley, about 25 miles southwest of the Iron Springs district and under similar geologic conditions. In California they are found in the Cave Canyon and other districts in San Bernardino County, in the Eagle Mountain district, Riverside County, in Shasta County, and elsewhere. In Nevada large deposits, estimated to contain at least 7,000,000 tons of magnetite and hematite, averaging 63 per cent of iron, are reported to occur in the Lovelocks district, in Humboldt and Churchill counties. Deposits also occur in Lyon County. In Washington deposits which probably belong to this group, although their relations are not known in detail, occur at a number of localities in the northeastern part of the State, in Stevens County. The ores are chiefly magnetite and hematite, though in part altered to limonite.

In Colorado iron-ore deposits occur near Ashcroft, in Pitkin and Gunnison counties, and in the White Pine and Cebolla districts, in Gunnison County. Those of the Ashcroft district occur on both sides of the Elk Mountains, at elevations between 11,000 and 12,000 feet above tide. The deposits are associated with limestones and igneous intrusives. They are of considerable size, the one on the northwest side of the divide being at least 300 feet on the strike and from 40 to 122 feet thick. Its total depth is not known, but it is proved to be at least 100 feet. The greater part of the ore is high in iron and sulphur, but low in phosphorus.

In New Mexico iron-ore deposits occur at Chupadera Mesa and at Fierro, in Grant County. The latter locality has been worked for some years, furnishing a large amount of ore for the Pueblo furnaces. The ore is associated with limestones and igneous intrusions, forming lenses at or near the contact between the two. It is accompanied by metamorphic minerals, as epidote and garnet, which are developed in the contact zone in great abundance. The ore is magnetite with subordinate amounts of hematite, and usually contains a small amount of copper. The greater part of the easily accessible high-grade ore has been mined out.

COMMERCIAL CLASSIFICATION AND SUMMARY OF ESTIMATES.

While the foregoing classification and grouping of the iron-ore deposits is a convenient one for purposes of description and for discussion of the basis and value of tonnage estimates, the grouping does not correspond with commercial conditions, and the estimates already given are therefore summarized by commercial grades and districts in the following table:

Estimates of iron-ore supplies of the United States.

Commercial districts (States).	Magnetite ores.			
	Nontitaniferous.		Titaniferous.	
	Available.	Not available.	Available.	Not available.
	Long tons.	*Long tons.*	*Long tons.*	*Long tons.*
1. Northeastern	160,000,000	111,500,000	90,000,000	100,000,000
2. Southeastern	[a] 12,500,000	23,000,000		
3. Lake Superior		4,500,000,000		25,000,000
4. Mississippi Valley				
5. Rocky Mountain	[a] 51,485,000	[a] 115,440,000		1,500,000
6. Pacific Slope	[a] 68,950,000	11,800,000		2,000,000
Total	292,935,000	4,761,740,000	90,000,000	128,500,000

[a] Includes some hematite.

1. Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Ohio.
2. Virginia, West Virginia, eastern Kentucky, North Carolina, South Carolina, Georgia, Alabama, east Tennessee.
3. Michigan, Minnesota, Wisconsin.
4. Northwest Alabama, west Tennessee, west Kentucky, Iowa, Missouri, Arkansas, east Texas.
5. Montana, Idaho, Wyoming, Colorado, Utah, Nevada, New Mexico, west Texas, Arizona.
6. Washington, Oregon, California.

Estimates of iron-ore supplies of the United States—Continued.

Commercial districts (States).	Hematite ores.			
	Specular and red.		Clinton.	
	Available.	Not available.	Available.	Not available.
	Long tons.	*Long tons.*	*Long tons.*	*Long tons.*
1. Northeastern	2,000,000	2,000,000	35,000,000	620,000,000
2. Southeastern	8,000,000	53,000,000	463,540,000	970,500,000
3. Lake Superior	3,500,000,000	67,475,000,000	10,000,000	30,000,000
4. Mississippi Valley	15,000,000	10,000,000		
5. Rocky Mountain	4,275,000	2,100,000		
6. Pacific Slope		10,000,000		
Total	3,529,275,000	67,552,100,000	508,540,000	1,620,500,000

Commercial districts (States).	Brown ores.		Carbonate ores.		Total supplies.	
	Available.	Not Available.	Available.	Not Available.	Available.	Not Available.
	Long tons.	*Long tons.*	*Long tons.*	*Long tons.*	*Long tons.*	*Long tons.*
1. Northeastern	11,000,000	13,500,000		248,000,000	298,000,000	1,095,000,000
2. Southeastern	54,400,000	168,000,000		62,000,000	538,440,000	1,276,500,000
3. Lake Superior					3,510,000,000	72,030,000,000
4. Mississippi Valley	300,000,000	560,000,000			315,000,000	570,000,000
5. Rocky Mountain	2,000,000	1,625,000			57,760,000	120,665,000
6. Pacific Slope		105,000			68,950,000	23,905,000
Total	367,400,000	743,230,000		310,000,000	4,788,150,000	75,116,070,000

1. Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Ohio.
2. Virginia, West Virginia, eastern Kentucky, North Carolina, South Carolina, Georgia, Alabama, east Tennessee.
3. Michigan, Minnesota, Wisconsin.
4. Northwest Alabama, west Tennessee, west Kentucky, Iowa, Missouri, Arkansas, east Texas.
5. Montana, Idaho, Wyoming, Colorado, Utah, Nevada, New Mexico, west Texas, Arizona.
6. Washington, Oregon, California.

FOREIGN IRON-ORE SUPPLIES.

In addition to the ore supplies included in the table given above, certain foreign deposits are so situated that they must depend, at least to a considerable extent, upon the American market, and are therefore to be considered practically a part of the available reserves. The most important of these sources of foreign supply are located in Canada, Newfoundland, Cuba, and Mexico. None of these countries has an abundant fuel supply, and therefore either the fuel must be imported or the ore exported. The history of the iron industry indicates that the latter is most likely to occur, particularly when the industry is already established and the chief market for the finished product is near the fuel supply. This tendency may be interrupted by artificial means, such as bonuses and tariffs, but such interference with the natural course of industrial development is only temporary, and in the long run the industry will gravitate to the point of the lowest cost of production.

CANADIAN ORES.

Recent explorations have shown the existence of considerable areas of the iron-bearing formations on the north shore of Lake Superior. The total tonnage of the iron formation in the Animikie, Michipicoten, and other north-shore districts is calculated at 93,600,000,000 tons. If the same proportion of this total be considered low-grade ore as in the Michigan and Minnesota districts it will amount to about 20,000,000,000 tons. Since these north-shore districts are not as yet thoroughly prospected, the ratio between high and low grade ores can not be definitely determined, but it is almost certainly much lower than in the Michigan and Minnesota districts. The best estimate of ore now available in these Canadian districts is 9,000,000 tons.

Deposits of iron ore of the igneous contact type are known to occur in British Columbia, and those on Texada Island have been mined to some extent. These deposits are estimated to contain at least 30,000,000 tons of ore of present commercial grade and probably a considerably larger amount of low-grade and deep ore not now available.

NEWFOUNDLAND ORES.

The most important of these are Clinton ores occurring on Belle Isle. Their area is definitely known and the doubtful factors are the proportion of ore below present commercial grade and the amount of available ore in beds known to extend under the ocean. The supply of available ore has been estimated at 30,000,000 tons, and the amount not now available may be several times this amount.

MEXICAN ORES.

Large deposits of iron ore are known to occur in various parts of Mexico. They are chiefly of the igneous contact and gossan types, and no estimate of any value can be made of their available tonnage. Remoteness from centers of iron production will prevent their extensive exploitation for the present, and they are therefore to be regarded as wholly within the unavailable class.

CUBAN ORES.

By far the most important foreign source of iron ore, measured by the extent of the supplies and their accessibility, is Cuba. The deposits are of two kinds, specular hematites of the Santiago district and brown limonites of the Mayari, Moa, Baracoa, Cubitas, and Pinar del Rio districts. The hematites have been worked extensively since 1884, and for a number of years have furnished more than 50 per cent of the total iron-ore imports. They are estimated to contain about 9,000,000 tons of ore, about half of which is actually measured.

The limonites are widespread residual deposits derived from the weathering of igneous rocks. The ore contains from 43 to 52 per cent of iron, phosphorus below the Bessemer limit, and between 1 and 2 per cent of chromium. These deposits are as yet practically undeveloped, but the more important ones have been fairly well prospected, and it is estimated that they contain an aggregate of 3,000,000,000 tons, at least one-third and possibly one-half of which may be regarded as now available. Most of the deposits are located near the northern coast of the island, so that they have the advantage of cheap water transportation to all parts of the Atlantic seaboard. They are without question destined to play an important rôle in the iron industry of the United States.

SUMMARY OF FOREIGN SUPPLIES.

The total estimated foreign supplies of ore sufficiently high-grade and accessible to mining and transportation to be at present available, and so located as to affect the iron industry of the United States, are shown in the following table:

Estimated foreign iron ores.

	Long tons.
Canada:	
British Columbia, magnetite chiefly	30,000,000
Lake Superior district, hematite chiefly	9,000,000
Nova Scotia, Clinton hematite	4,000,000
Newfoundland, Clinton hematite	30,000,000
Cuba:	
Santiago district, hematite	5,000,000
Mayari, Moa, Baracoa, Cubitas, and Pinar del Rio districts (limonite)	1,500,000,000
Total	1,578,000,000

IMPORTS AND EXPORTS.

The total imports of iron ore since 1889 have been 3 per cent of the domestic production for the same period. They have shown great annual fluctuations, responding quickly to changes in industrial conditions. Since 1904 there has been a steady and rapid increase in imports, and this increase may be expected to continue in the future even more rapidly with the expanding development of the Cuban limonite deposits.

The extent to which foreign ores are now supplying the market is shown by the following table of imports:

Imports of iron ore from foreign countries, 1889-1907.

Year.	Cuba.	Newfoundland and Labrador.	Quebec, Ontario, etc.	Spain.	Other countries.[a]	Total.
	Long tons.	*Long tons.*	*Long tons.*	*Long tons.*	*Long tons.*	*Long tons.*
1889	243,255	14,450	4,091	298,568	293,209	853,573
1890	351,814	6,320	22,211	512,933	353,552	1,246,830
1891	257,189	....	2,126	323,771	329,778	912,864
1892	307,115	....	8,606	236,957	253,907	806,585
1893	349,977	....	372	99,640	76,962	526,951
1894	140,025	....	443	15,067	11,772	167,307
1895	367,255	....	....	77,594	79,304	524,153
1896	380,551	20,800	....	121,132	160,323	682,806
1897	383,820	29,250	....	66,193	10,707	489,970
1898	165,623	....	....	13,335	8,250	187,208
1899	360,813	77,970	....	145,206	90,093	674,082
1900	431,265	140,535	5,588	253,694	66,749	897,831
1901	526,583	[b] 79,360	163,383	180,810	16,814	966,950
1902	696,375	81,920	203,824	153,527	29,824	1,165,470
1903	613,585	[b] 86,730	169,681	94,720	15,724	980,440
1904	364,630	5,400	77,887	36,810	2,886	487,613
1905	539,935	5,600	104,096	191,861	4,159	845,651
1906	639,362	[b] 125,395	57,890	171,870	65,873	1,060,390
1907	657,133	89,685	26,878	296,318	159,154	1,229,168
Total	7,776,305	763,415	847,076	3,290,006	2,029,040	14,705,842

[a] Belgium, Brazil, British Columbia, England, France, French Africa, French West Indies, Germany, Greece, Italy, Mexico, Netherlands, New Brunswick, Norway, Nova Scotia, Oceania, Portugal, Sweden, Turkey in Asia, Turkey in Europe, Venezuela, etc.
[b] Includes Newfoundland only.

The exportation of iron ores has fortunately never assumed large proportions, as shown by the following table:

Exports of iron ore from the United States, 1899-1907.

Year.	Quantity.	Value.
	Long tons.	
1899	40,665	$76,287
1900	31,460	154,756
1901	64,703	163,465
1902	88,445	294,168
1903	80,611	255,728
1904	213,865	458,823
1905	208,017	530,457
1906	265,240	771,839
1907	278,208	763,422
Total	1,271,214	3,468,945

This export consists chiefly of Lake Superior ores shipped to Canadian furnaces for mixture with local ores. It contains also some high-phosphorus ores from the Adirondack district shipped to Germany. This movement has practically ceased, owing to increased home demand for these ores.

WASTE IN MINING AND REDUCTION.

Where iron ore occurs in the form of bedded deposits and is mined underground, waste is apt to occur from the same causes as in coal mining. These are the leaving of pillars, often unnecessarily large, to support the roof, the leaving of low-grade ore in the mine where it can subsequently be recovered only with difficulty, if at all, and the breaking down of an overlying bed where the lower of two beds in the same territory is mined first. These sources of waste are confined largely to the Clinton ores, and the available facts are insufficient for closely estimating its amount, but the proportion of recovery varies with local conditions between 75 and 90 per cent and is undoubtedly increasing with improvement in mining methods. In computing the available tonnage of the Clinton ores an average recovery of 75 per cent has been assumed. Portions of the Clinton ore beds at present considered of no value because of shale partings and consequently left in the ground might be mined at many points if the shale could be separated from the ore economically. Improvement in cleaning and concentrating methods will undoubtedly make the recovery of much ore of this character possible. In the steeply dipping magnetite and hematite beds practically all ore up to the required grade is mined out, and the ground is generally left in such condition that the mines can be reopened for the recovery of lower-grade ores.

In surface workings waste is confined largely to small operations where quick returns are required, and systematic development is impossible. In such cases much ore is lost by dumping barren strippings and low-grade ore together, so that it can be recovered only with difficulty, if at all. Where the operations are on a large enough scale to warrant the installation of mechanical excavators, and a proper ore-dressing plant, this waste does not occur and practically all the ore in a deposit is recovered. Some waste of finely divided ore occurs in the process of washing brown ores to remove the associated clay, and there is still room for improvement in operations of this kind. If it becomes necessary to mine material which is below the grade of present requirements, but which contains enough iron values to make it a possible ore in the future, such material is stacked so that it will be available at any future time. This policy has been most consistently followed in the Lake Superior district, and when such low-grade ores are required large amounts will be available merely at the cost of loading on the cars.

In the early days of iron making an appreciable part of the iron in the ores went into the slag and was permanently lost. Blast-furnace practice, however, has been so greatly improved in recent years that this source of waste is eliminated and practically all of the iron in the ore is now recovered.

PRODUCTION AND USE OF IRON ORES.

The beginning of the iron industry in America dates from 1645, when a furnace and forge were built at Lynn, in the province of Massachusetts Bay. In the century following a large number of small furnaces and bloomeries were operated in the New England colonies, using bog ores almost exclusively, and during this period Massachusetts was the chief iron producer. In 1734 the richer brown ores of western Connecticut and southern New York were opened and largely replaced the bog ores. The manufacture of iron was begun in eastern Pennsylvania in 1716, and a few years later in northern New Jersey, using the rich magnetites of that region. The industry had a rapid growth, notwithstanding the restriction placed upon it, and at the time of the Revolution there were over 140 furnaces and bloomeries in operation in this district.

In the fifty years preceding the Revolution a number of furnaces and forges were in operation in Maryland, Virginia, and the Carolinas, located for the most part on the tide-water streams of the coastal plain and using the brown ores associated in small quantities with the clays and sands of the coastal formations. The deposits of magnetite in the crystalline rocks of the Piedmont were also worked during this period to a slight extent.

After the close of the Revolution the iron industry expanded rapidly, following the westward progress of settlement, and had reached western Pennsylvania and the Appalachian Valley of Virginia and Tennessee before the close of the eighteenth century. In the first third of the nineteenth century it had reached as far west as Missouri and north to Michigan. During this period conditions favored a wide distribution of the industry. Charcoal was the only fuel used, and this could always be obtained in the immediate vicinity of the ores. Transportation facilities were very poor, and the small furnaces so situated as to supply the local demand, even working on inferior ores, could compete with the older establishments at a distance. About 1840 a revolution was effected in the iron-making industry by the introduction of anthracite and bituminous coal as a furnace fuel. The capacity of the furnaces was rapidly increased, and with improvement in transportation facilities the industry was concentrated at a relatively few points advantageously located with reference to the new fuel supply. Under the changed conditions the ore was brought to the fuel, hence only the best ore and the largest deposits were worked, and many districts, as Ohio and Kentucky, which had been heavy producers, were practically abandoned. With the decrease in average iron content of ores going into the furnaces, due to the depletion of the richest deposits, there is at present a notable tendency toward decentralization of the industry and a consequent reopening of abandoned ore deposits, though it will never revert to the conditions which prevailed during the charcoal period.

The statistics of iron production during the early years of the industry were not collected, and the total amount of iron ore consumed can not be determined. Not until 1889 were annual statistics of ore production collected, though they are available for the two preceding census years 1870 and 1880, and the annual production of intermediate years may be derived from the known production of pig iron as far back as 1870. Basing an estimate upon the average pig iron production shown for census years prior to 1870, the total iron ore produced from 1810 to 1869 was approximately 49,656,000 tons, and on the annual production of pig iron from 1870 to 1888 it was 153,758,000 tons. These amounts added to the 475,162,000 tons produced from 1889 to 1907 give a grand total of 678,576,000 tons produced since 1810. The amount produced during the Colonial and Revolutionary periods and up to the third census in 1810 is so small in comparison with the total production since that time as to be a negligible quantity.

In deducing the iron ore production from the production of pig iron, it should be borne in mind that a small proportion of this iron was made from imported ores and also that some pig iron is made from other materials than natural ores, as blue billy, zinc residues, rolling-mill cinder, scrap, etc. On the other hand, iron ore is used for other purposes, as in the manufacture of paint, as a fix or fettling in puddling furnaces, and as a flux in silver smelting, and the amount so used practically offsets the amount of material other than iron ore charged into the blast furnaces.

The production of iron ore from 1870 to 1907, inclusive, is shown on the accompanying diagram (p. 110), along with the production of pig iron and steel for the same period.

The curve representing the production of pig iron shows more fluctuations than the ore curve, and that representing production of steel more than the pig-iron curve. In other words, the production of steel responds most promptly to varying industrial conditions. Thus the production of steel in 1907 shows practically no increase over 1906, while the rate of increase in ore is above the average for the preceding eighteen years. This is explained by the fact that the industrial depression of 1907 came so late in the year that it only slightly affected the output of iron ore, particularly in the Lake

Superior district, where mining is more active in summer than in winter. It is practically certain, however, that the output of ore for 1908 will show a decided decrease similar to, and probably larger, than that which marked the years 1893–94 and 1904. The years 1892,

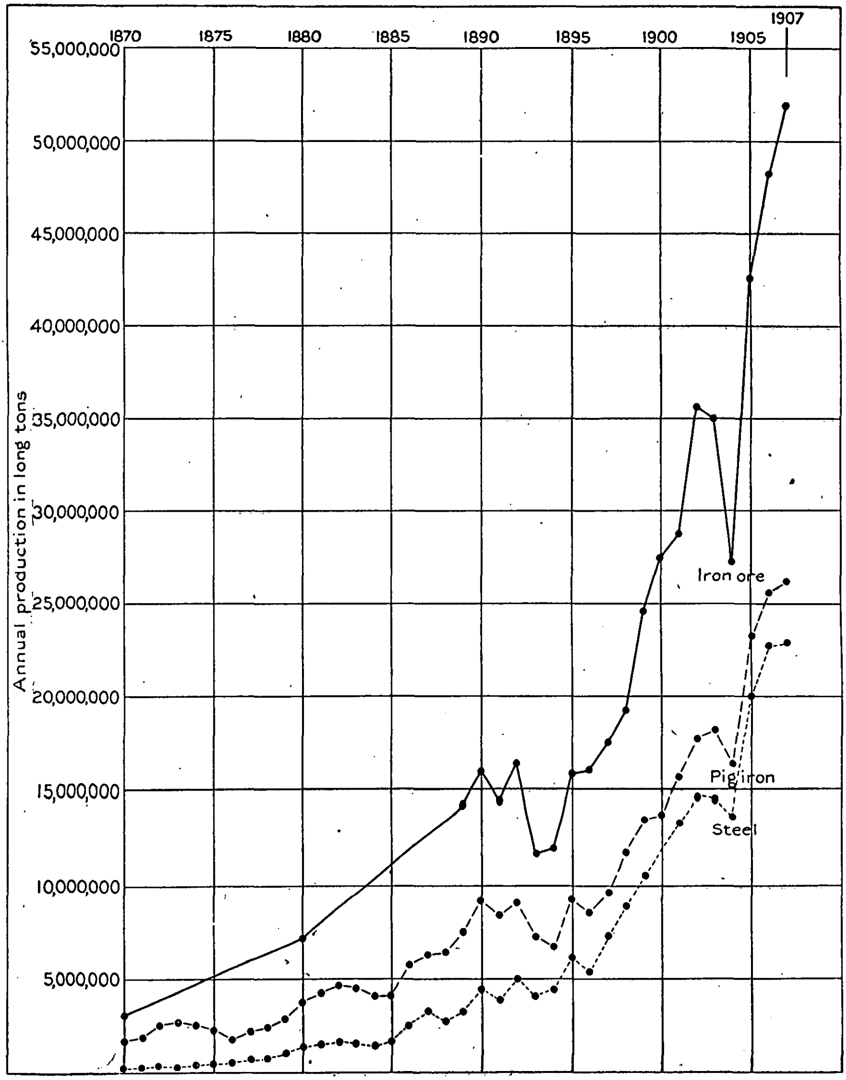


FIGURE 2.—Curve showing the production of iron ore, pig iron, and steel in the United States, 1870–1907, in long tons.

1902, and 1907 occupy maximum points in the curve, and each is followed by a decided drop and rapid recovery far beyond the preceding maximum. It may be safely predicted that the curve will resume its upward trend in 1909 after the drop of 1908.

The distribution of the production since 1889 among the varieties of ore enumerated in the chemical classification is shown in the following table:

Production of iron ores in the United States, by varieties, 1889–1907.

Year.	Magnetite.	Hematite.	Brown ore.	Carbonate.	Total.
	Long tons.	*Long tons.*	*Long tons.*	*Long tons.*	*Long tons.*
1889	2,506,415	9,056,288	2,523,087	432,251	14,518,041
1890	2,570,838	10,527,650	2,559,938	377,617	16,036,043
1891	2,317,108	9,327,398	2,757,564	189,108	14,591,178
1892	1,971,965	11,646,619	2,485,101	192,981	16,296,666
1893	1,330,886	8,272,637	1,849,272	134,834	11,587,629
1894	972,219	9,347,434	1,472,748	87,278	11,879,679
1895	1,268,222	12,513,995	2,102,358	73,039	15,957,614
1896	1,211,526	12,576,288	2,126,212	91,423	16,005,449
1897	1,059,479	14,413,318	1,961,954	83,295	17,518,046
1898	1,237,978	16,150,684	1,989,681	55,373	19,433,716
1899	1,727,430	20,004,399	2,869,785	81,559	24,683,173
1900	1,537,551	22,708,274	3,231,089	76,247	27,553,161
1901	1,813,076	24,006,025	3,016,715	51,663	28,887,479
1902	1,688,860	30,532,149	3,305,484	27,642	35,554,135
1903	1,575,422	30,328,654	3,080,399	34,833	35,019,308
1904	1,638,846	23,839,477	2,146,795	19,212	27,644,330
1905	2,390,417	37,567,055	2,546,662	21,999	42,526,133
1906	2,469,294	42,481,375	2,781,063	17,996	47,749,728
1907	2,679,067	46,060,486	2,957,477	23,589	51,720,619
Total	33,966,599	391,360,205	47,763,384	2,071,939	475,162,127
Percentage of totals for nineteen years	7.1	82.4	10.1	0.4	....
Percentage of total for 1907	5.2	89.1	5.7	....	....

The present relative importance of the several varieties is shown by the percentage and also the increasing importance of the hematite as compared with the other varieties. The combined total productions of brown ore and carbonate for the nineteen years is 2,000,000 tons less than the total production of all varieties for the year 1907.

The distribution of production for 1906 and 1907 among the six commercial districts is shown in the following table:

Production of iron ores in the United States, by commercial districts, in 1906 and 1907.

District.	1906.		1907.	
	Quantity.	Percentage of total.	Quantity.	Percentage of total.
	Long tons.		*Long tons.*	
1. Northeastern	2,582,666	5.40	2,822,822	5.45
2. Southeastern	6,208,140	13.00	6,197,360	12.00
3. Lake Superior	38,035,084	79.66	41,638,744	80.50
4. Mississippi Valley	117,570	.25	230,435	.45
5. Rocky Mountain	806,268	1.70	831,258	1.60
6. Pacific slope	(a)	....	(a)	....
Total	47,749,728	100.00	51,720,619	100.00

[a] The small production of California and Washington is included in the production of the Rocky Mountain district.

These figures indicate the commanding position of the Lake Superior district in the iron industry with 79.66 and 80.60 per cent of the total production for the two years.

DURATION OF THE IRON-ORE SUPPLY.

Predictions of the date of exhaustion of the iron-ore reserves involve a number of unknown factors, each of which adds to the uncertainty of the result. Among these factors the following may be mentioned:

1. The uncertainties of the estimates of reserves and the difficulty of fixing the ratio of the two classes have been fully explained in the sections devoted to the description of the ore deposits.

2. The extent to which imported ores will supplement the domestic supply can not be foretold, but it will be an increasingly important factor.

3. The extent to which the reserves will be increased by the discovery of new ore bodies can not be estimated, but it is highly improbable that all the important iron-ore deposits are now known.

4. The ores of the first class will not be entirely exhausted before utilization of the second class begins, and changing conditions, particularly of transportation and metallurgy, will continually shift the line dividing the two classes.

5. The stock of metal which can be reworked is constantly increasing and must eventually reduce the demand for metal obtained directly from the ores.

6. The substitution of other materials for metal now used for certain purposes, particularly for construction, will reduce the consumption to an extent which can not be even approximately estimated, and, on the other hand, the proportion of structures into which iron enters as an important constituent will undoubtedly increase.

7. The per capita consumption of iron ore has shown a rapid increase since the beginning of the iron industry. For 1907 and the four preceding census years it has been as follows: 1870, 180 pounds; 1880, 313 pounds; 1890, 560 pounds; 1900, 806 pounds; and 1907, 1,344 pounds.

8. The increasing cost of iron due to the increase in cost of fuel and the use of lower-grade ores requiring an increased amount of fuel per ton of iron smelted, will induce greater economy in the use of the metal; on the other hand, improvements in metallurgy will tend to secure a larger yield of metal for a given expenditure of fuel and power and may substitute low-grade fuel for the higher-grade coal now required in the blast furnace.

The most striking feature of the iron-ore production curve is the remarkable rate of increase shown in the period covered. Taking the production since 1870 by decades and estimating the last two years of the present decade, 1908 and 1909, the percentage rate of increase for each decade over the one preceding is shown in the following table:

Production of iron ore by decades and rate of increase.

Decade.	Quantity.	Percentage of increase.
	Long tons.	
1870-1879	43,770,527	....
1880-1889	91,043,854	108.0
1890-1899	163,989,193	80.1
1900-1909	[a] 392,000,000	138.0

[a] Approximate.

Each of the above decades, as shown by the production curve, contains a depression in which there was an actual decrease in production, so that they may be taken as fairly representing the tendency of the industry. These rates of increase are such that they do not permit the construction of a curve on which predictions for the future can be based. A comparison of the first and second rates, 108 and 80.1, would indicate a rapid decrease in the rate of increase, which, if continued, would have placed the date of maximum production about 1930. But a comparison of the second and third rates, 80.1 and 138, would indicate a rapid increase in the rate of increase. If the average rate of increase by decades, 108.7 per cent, should be continued, it would require the production in the next three decades of 6,088,000,000 tons. But the ore supply now available in the United States is estimated at 4,788,000,000 tons, which is only 78 per cent of the amount needed on this assumption. It is evident, therefore, that the present average rate of increase in production of high-grade ores can not continue even for the next thirty years, and that before 1940 the production must already have reached a maximum and begun to decline, and a very large use must be made of low-grade ores not now classed as available. The second condition, with its consequent greatly increased cost of iron, is the only thing which can prevent a decline in the iron industry, measured by the amount of pig iron produced, within the next thirty years, unless there is in the meantime very greatly increased importation of foreign ores.

In view of the many factors entering into the problem, the tendency of which is not always determinable, to say nothing of the weight that should be given them, any further prediction as to the date of exhaustion of the iron-ore supplies is so uncertain as to be wholly unprofitable and unwarranted.

RESOURCES OF THE UNITED STATES IN GOLD, SILVER, COPPER, LEAD, AND ZINC.

By Waldemar Lindgren.

INTRODUCTION.

DISTRIBUTION OF ORES.

The ores of gold, silver, copper, lead, and zinc occur as a rule in localized deposits of varying form, depth, tenor, and geologic relations. There are no wide areas underlain by strata of ore with maintained characteristics. The ore deposits are exceptional occurrences. They are concentrated, it is true, in a number of localities, but the bodies are ordinarily of very irregular form, and it is difficult to predict what each new level in a shaft, each new drift on a level, will disclose. Some of the large companies mining copper, lead, or zinc ores have extensive reserves blocked out by actual development work or by borings, but the ore developed is rarely sufficient for more than a few years' work. The majority of the companies would undoubtedly decline to furnish detailed information on this subject.

The distribution of values is even more capricious in precious-metal mines than in base-metal mines, and in the case of gold the number of companies operating lode mines with large reserves can be counted on the fingers. Concerning deposits of gold-bearing gravels or placers, a somewhat more accurate statement can be made as to the probable extent of resources. These remarks serve to make clear the impossibility of ascertaining even the approximate extent of the total supply of metallic ores. The best that can be done is to forecast in a rough way the probabilities of the immediate future on the basis of the experience of the past. In doing so, it is well to bear in mind that many of the predictions ventured on this subject during the last fifty years by able men have proved very wide of the mark.

The conclusions reached in this report are based chiefly on investigations by the geologists of the United States Geological Survey.

MINERAL LANDS OF THE UNITED STATES.

The mineral-bearing lands still owned by the United States are largely confined to the Cordilleran States. The mineral lands of the Southern Appalachian States are privately owned, and as far as the total production is concerned they cut a small figure. Likewise, the copper-bearing lands of Michigan and the lead-zinc lands of Missouri and other States of the central valley have passed into private hands. There remain the States of Colorado, Wyoming, Montana, Idaho, Utah, Nevada, Washington, Oregon, and California, as well as the Territories of Alaska, Arizona, and New Mexico, in which there still exists a large aggregate area of mineral land belonging to the United States. The extent of the mineral land of the United States still owned by the Federal Government is an unknown quantity because (1) the mineral lands have never been segregated and surveyed, and (2) a very large acreage is simply held by assessment work, and the present laws do not require that such claims shall be surveyed or registered. It is true that the majority of claims on which valuable mines have been developed have passed to patent. But there are thousands, in fact, hundreds of thousands of claims on which mineral has been discovered, which are held by annual assessment work, and of which the General Land Office has no record whatever. Even many important producing mines, and practically all placer mines of Alaska, are thus held. This condition is made much worse by the fact that according to present laws anyone—individual or company—can locate an unlimited number of claims provided the assessment work is performed. As no assessment work is required until a year to two years after discovery, this rule works out so that a newly discovered camp is completely covered by locations by the first comers, and its growth may be seriously interfered with. In case of specially valuable discoveries the early arrivals are thus granted an unreasonable privilege which is always abused. The process is well known throughout the West, and is popularly known as "claim hogging."

The first steps toward ascertaining the area of mineral land still belonging to the United States would seem to be: (1) Survey and segregation of mineral lands; (2) registration of all mineral claims at the land office of the district.

Any estimates on the basis of available data are useless.

The first requirement, segregation of mineral lands, is no doubt easier to demand than to execute. There is no possibility, as with coal deposits, to segregate large areas with the confident knowledge that the mineral exists below them. For instance, a mountain range may present a favorable aspect from a geologic standpoint for the occurrence of metals, and yet no deposits may be found in it except perhaps within one limited area. However, the possibility always remains that some careful and deeper prospecting may reveal ores in the part hitherto considered barren.

A worse complication is involved when the land is valuable for several purposes. It may be good agricultural land; even if situated in the mountain regions it may, as is frequently the case in California, be valuable for horticulture and viticulture, or for pasture. Here is a conflict between permanent and temporary value. The land will always produce fruits, but the gold deposit below it will, in all probability, be exhausted in a limited time, very soon, indeed, in the case of many buried gravel channels. Such conflicts have caused much loss and annoyance in California. How can these two values be compared and measured?

A difficulty even more troublesome arises when the land is valuable for both its mineral and its forest. Here, however, we have to measure two more commensurate values, both of more temporary character than in case of agricultural lands. The value of the forest can usually be measured with some accuracy. The value of the mineral on the same land can usually not be measured with exactness. Very often the former will exceed the latter, as far as surface developments go, and then the question arises whether it is justifiable to interfere with free prospecting and search for metals in order to more effectively preserve the forests.

It would seem that the present interminable conflicts could be avoided only by a separation of the mineral and forest rights, while retaining for agricultural patents the right to possible later discoveries underneath the ground. The forest lands have great value, and as long as human nature remains what it is even the bona fide miner will continually attempt to gain possession of them by unduly extending his mineral locations. Many mining districts are covered with a scant growth of forest, barely enough for the miner's needs for timber and fuel. Such lands should not be classified as forests.

WASTE.

The prevention of waste in mining and reduction processes is a most important subject. Whatever our views of future necessities, it is clearly not right to carelessly waste the metallic treasures of the earth, and in this direction much can be accomplished. The loss is rather in processes of concentration and reduction than in mining. In some cases pillars of ore are left, but the shape of the deposits is generally such that all the ore can be extracted without much loss. In industries like copper mining, where the term "ore" has rapidly changed its meaning within the last decade—where, in other words, ore containing 1, 2, or 3 per cent of copper can now be mined profitably where it was formerly considered waste—it is clear that large bodies must be left now which later may possibly be extracted with profit. But this ore is, of course, not lost unless the whole mine goes to wreck.

In concentrating and milling the greatest losses occur and the percentage of these is largest in the low-grade deposits. In the earlier days of gold and silver milling enormous amounts of rich tailings were sent down the creeks and gulches and permanently lost, largely because of conviction that the values could not be recovered, partly perhaps because of disinclination to let it be known that the tailings contained any values. Matters have changed in this respect, and tailings are now generally stored with a view to possible reworking. No doubt the States could aid this practice of economy by legal requirement of such storage, a policy which besides is desirable in order to avoid contamination of the water supply.

The losses of gold, silver, copper, and lead in smelting are generally not large, and, moreover, the slag is necessarily and easily stored. In many cases the slags of earlier years have been worked over. By far the greatest losses take place in the concentration of copper, lead, and zinc ores. They probably reach their maximum in zinc ores or in copper ores with soft metallic minerals like chalcocite, and here often attain 30 per cent or even 40 per cent. These operations are also conducted on a large scale, making storage of tailings difficult, but the same principle should be applied by legal requirements wherever possible. Somewhat better conditions now prevail in Missouri than formerly, but some years ago it was not at all uncommon to have losses in zinc concentration reaching 40 per cent.

No doubt it will be impracticable, under our system of government, to compel mine owners to prevent unnecessary waste by prescribing certain working methods. Probably no European state has ever gone so far. Storage of tailings will probably prove to be the best remedy if it can be legally enforced.

It is perhaps in the utilization of by-products that we have most to learn, but the standpoint is naturally taken by miners and smelting men that if it can not be done with profit it had better not be done at all. I refer specially to the smelter fumes and to the extremely large quantities of sulphur and arsenic that are driven off in the air, sometimes with great damage to the surrounding agricultural districts. The case of arsenic is especially interesting. The statement is made by F. L. Hess [a] that—

> Enormous quantities of arsenic in fumes continually escape from the smelters of the country, while at present comparatively little arsenic is saved. Harkins and Swain (Jour. Am. Chem. Soc., vol. 19, 1907, pp. 970–998) state that in August, 1905 (when the experiments were made), from the Washoe smelter, which works exclusively upon Butte copper ores, 59,270 pounds of arsenic trioxide per day were passing through the stack. This is equivalent to 10,817 short tons per year, and is exclusive of what arsenic trioxide was saved from the flues. At 5 cents per pound, the lowest price for which white arsenic sold in 1907, this waste product of one year would be valued at $1,081,700. The waste arsenical fumes at this plant alone amount to more than six times the domestic saving of arsenic trioxide, and to much more than the combined production and imports of arsenic in the United States each year.

[a] Mineral Resources U. S. for 1907, separate on "Antimony and arsenic," p. 9.

At the Butte reduction works and the Great Falls smelter other great quantities of more or less arsenical Butte copper ores are treated, from which no saving of arsenic is known to have been made, and from which the losses must be very great.

In Utah both the Bingham and the Tintic copper ores are arsenical, and no saving has yet been made from them, though immense quantities of ore are smelted.

It is recognized that in handling a low-priced product like arsenic, saving can not be carried to extreme refinement without becoming unprofitable. However, arsenic is now being extracted from sulphuric acid at a number of establishments in England, and both products are cheap articles. If even one-half of the arsenic wasted were saved, the market in this country would be glutted. However, without taking account of the possibility of greater demand, if there were a greater supply at a somewhat lower price, there will in time probably be some plan devised for the better saving of smelter fumes, through the operation of which it will be unnecessary for this country to import arsenic while so much is continually being wasted.

Smelter fumes occupy a similar position to tailings in mills, but they can not, of course, be stored. On the contrary, they spread over the country, frequently damaging the vegetation near the smelter, and the compulsory saving of the sulphur and arsenic contained will probably soon, in most cases, be required by law.

In many cases the waste in mining and milling is the result of ignorance. Dissemination of knowledge and investigation of methods by bureaus of the Federal Government and the States will do much to check the waste.

GENERAL CONCLUSIONS.

The individual reports on the separate metals will show that the resources in each case are very large, but that they can not (with few exceptions) be measured with any accuracy. To give definite figures representing our metal supply is quite out of the question. It will be shown that our resources of silver, copper, and zinc are large and that a moderate rate of increase in production can be maintained probably for the next twenty years at least. In case of lead it is not probable that the production can be greatly increased.

While it is true that, with a continuation of the present increasing rate of production, the known reserves, workable under present conditions, may be exhausted before the middle of the present century, this prediction should not be announced without important qualifying clauses. The nature of the case prevents a full knowledge of our resources. They are developed by mining operations only, and exploration does not materially anticipate unusual demand. Ten years ago a review of our metallic wealth would have revealed a far greater shortage in the supply of metals than is now believed to exist, and it is probable that, in case of some metals at least, ten years from now our resources will be known to be greater than they are at present. The higher grade of ores of copper and lead are growing scarce, but improvements in technologic processes, by lowering the cost of reduction, have added great quantities of lower-grade material to our available ore supply, and will probably continue to do so. With increasing demands quantities of old metals will be returned to use. The importance of this factor is great, but it is difficult to measure. In case of gold it does not seem likely that, on the basis of present developments and processes, our production can be made to greatly exceed $110,000,000 per annum for the next twenty years. And on the same basis it would seem likely that after some such period the gold production would gradually decrease.

If we were sure that the development of the world would proceed indefinitely on the same lines as those of to-day; that metals would have the same value; that the same metals would be used for the same purposes; then it might be possible (to use an expression of Professor De Launay [a]) "to strike a balance between us and our descendants." We have not this knowledge. We may forecast what is likely to happen and what our needs will be in the metal industry, for the next ten, twenty, possibly fifty years. The conditions and developments in the more distant future are completely beyond us.

It is reasonably certain that the industrial development of the world will continue on an ever increasing scale. But who can tell us what methods and materials will be used, and what new discoveries in little explored continents will disclose? Substances now eagerly sought may then be of little value; reserves established by the States may be useless and simply serve to restrict the present development. Legislative interference with production of metals is likely to be futile and probably can not in the long run successfully interfere with the operation of economic principles based on laws of supply and demand.

GOLD.

PRODUCTION OF THE UNITED STATES.

Since 1892 the gold production of the United States has increased at a very rapid rate. An output of $60,000,000 was recorded in 1852 and 1854, shortly after the discovery of the California placers. From that time the production decreased gradually to $30,000,000 in 1883 and 1884 and then rose slightly, remaining at about $33,000,000 from 1885 to 1892. The effect of the Cripple Creek discoveries and of the application of the cyanide process became apparent after 1892 and the production steadily mounted to about $80,000,000 in 1902. A serious falling off in Colorado reduced the total in 1903 to $73,500,000, but during the next four years in consequence of the discoveries in

[a] De Launay, L., La conquête minérale, Paris, 1908, p. 379 et seq.

Alaska and the development of the dredging industry in California, there was a renewed rise which culminated in a production of over $94,000,000 in 1906.

In 1907 the output fell to $90,400,000, but a considerable increase is probable for 1908. The causes of the decrease in 1907 were the generally disturbed financial conditions, labor troubles, and a scarcity of water in Alaska.

The output of the United States is shown in the accompanying diagram. (See Pl. VI.)

PRODUCTION OF THE WORLD.

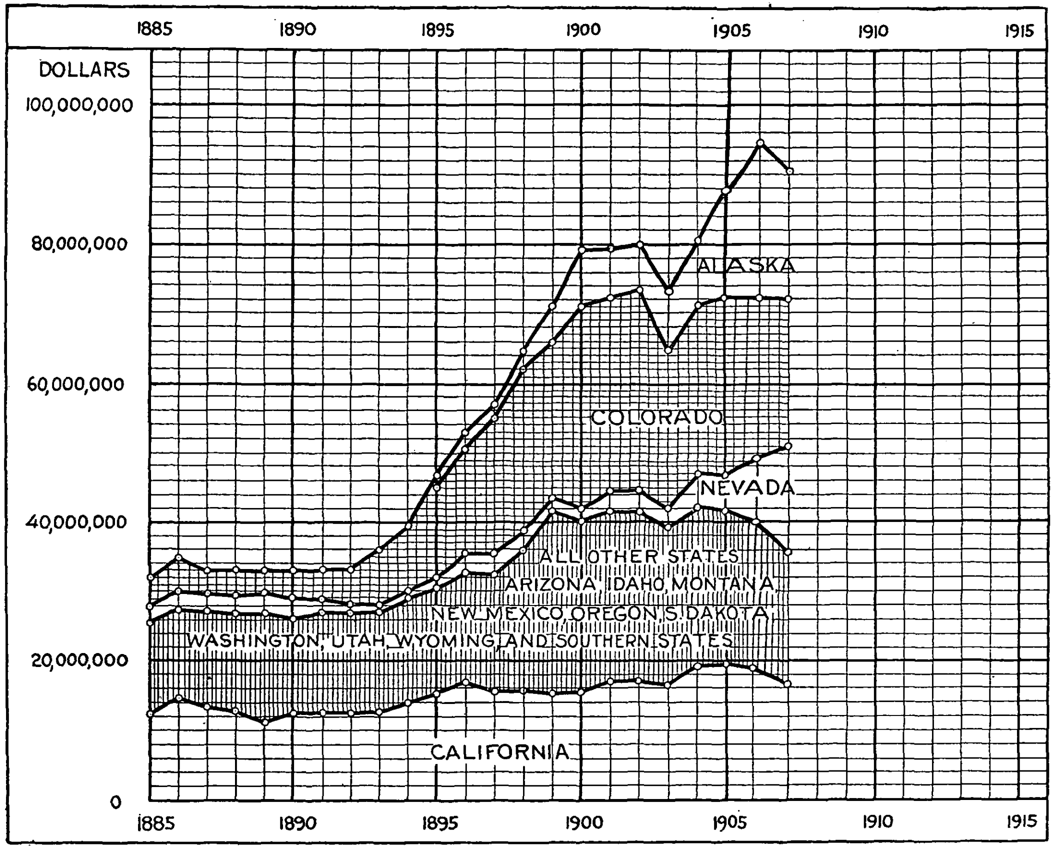
The rapid increase in the annual production of gold of the world is a feature which has been the subject of much discussion in its relation to the monetary systems and financial affairs generally. The facts are best brought out in the diagram. (See Pl. VII.) California and Australia in the early fifties brought the production rapidly to $180,000,000 from about $10,000,000 in 1830. The output in the earlier part of the century was largely derived from Russia. The gradual decay of placer mining in California and Australia reduced the yield for the world to nearly $100,000,000 about 1886. In the period from 1885 to 1890 numerous discoveries in South Africa, in Western Australia, and in Colorado changed the aspect of the industry.

The cyanide process, which gave better extraction at reduced cost, was introduced about this time. In South Africa especially this process has proved of the utmost importance. A little later discoveries were made in Alaska, Nevada, the Canadian Yukon, Mexico, Rhodesia, and West Africa, notwithstanding the assertion made by many that no further important supplies of gold were likely to be found.

Thus, since 1887 the production of the world has been trending upward, except for the temporary decline due to the Boer war, and in 1907 was about $412,000,000. It will be observed that Africa now (1907) contributes about $151,000,000, or one-third of the world's production, and of the African output about $133,000,000 comes from a small district in the Transvaal.

Barring new and unexpected discoveries it is believed that the world's production will not increase hereafter at the recent rapid rate of advance. It is believed that the maximum production has nearly been reached in the Transvaal, although the present output can be maintained for a long time, probably for more than thirty years. The output of Australia from present indications is more apt to decline than to increase.

As indicated by the diagram, the production of Russia forms a solid and constant substratum on the permanence of which it is fair to rely. A continued increase in the United States is scarcely to be



PRODUCTION OF GOLD OF THE UNITED STATES AND OF THE PRINCIPAL STATES AND TERRITORIES FROM 1885 TO 1907.

expected, although the recent history of gold mining in Nevada shows what unsuspected riches may lie for decades within easy reach. It is true that there are large unprospected territories in South America which with developing lines of communication may produce much gold, but on the whole the probabilities of the immediate future are rather in favor of maintenance of the present level of output than of a further sensational advance.

RESOURCES OF THE UNITED STATES.

The diagram (Pl. VII) shows that the United States production can, for present purposes, be divided into five parts. In 1907 Colorado, Alaska, California, and Nevada in the rank indicated contributed each from $15,000,000 to $20,000,000 to the total output. The remaining fifth part, approximately $19,000,000, came from Utah, South Dakota, Montana, Arizona, Idaho, and Oregon, the amount from the remaining States (southern Appalachian region, New Mexico, Washington, and Wyoming) being negligible.

IDAHO AND OREGON.

Great constancy has been shown by Idaho and Oregon in their gold output, which for each State generally is below $2,000,000 per annum and may be expected to continue on the same basis for many years to come. The product is from placers and gold-quartz veins.

SOUTH DAKOTA.

In South Dakota the output has varied since 1889 from $3,000,000 to $7,000,000. Of this about $5,000,000 is derived from the Homestake mine, the most productive gold mine in the United States. The total yield of this mine approaches $60,000,000. A large tonnage of low-grade ore (about 1,400,000 tons per annum) is treated in a mill with 1,000 stamps. The deposit, as far as known, does not approach exhaustion; the shafts have not attained great depth. The blanket deposits in limestone may be exhausted at an earlier date than the Homestake, though the reserves appear to be fairly large. It is likely that South Dakota will be able to maintain its production for a long time.

ARIZONA.

Arizona has for many years supplied from $1,000,000 to $3,000,000, which is derived about equally from the copper ores of United Verde, Globe, and Bisbee on one hand, and the gold-quartz mines of Yavapai, Mohave, and Yuma counties on the other hand. From neither source is much falling off to be expected for the next ten years; a moderate increase is more probable.

MONTANA.

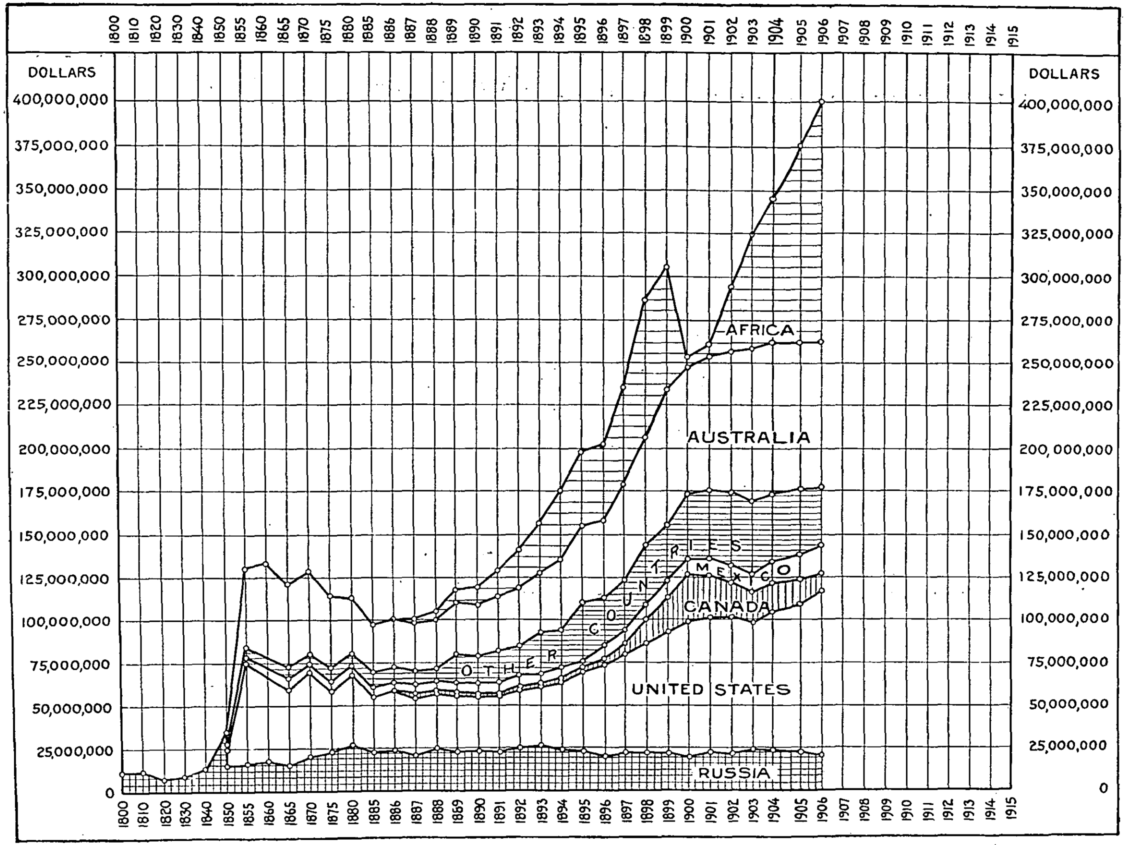
Montana has long maintained a steady gold production ranging from $3,000,000 to $4,000,000. For some years $1,000,000 has been derived from the Butte copper ores, and an equal amount from cyaniding the quartzose ores of Fergus County. The latter supply, however, has recently shown a sharp decline. The balance of the State total has come from a great number of small gold and silver mines in several counties. It is not likely that the production of Montana in the near future will sink below $3,000,000.

CALIFORNIA.

The California production is notable for its constancy. Since 1885 the State has annually supplied from $12,000,000 to $19,000,000 in gold. The rise noted in the diagram during the last few years is largely due to the development of the dredging industry. In 1907 the State produced $16,900,000, which, disregarding some minor sources, may be divided as follows: Quartz mines, $9,400,000; copper mines, $350,000; placer mines, $6,800,000. The production from quartz mines has of late decreased, but it may be relied upon to continue, with fluctuations, for a long period. There are few very large mines, but there are many which have shown ability to maintain moderate production for many years past. Few of the mines have ore developed for more than two or three years, and even approximate figures as to future reserves are out of the question. On the other hand, a long-continued and steady output gives assurance of a continuance for a long period of years, with probable ultimate diminution. The gold from copper ores will increase, and may in a few years reach $1,000,000.

The placer-mining industry of California presents some interesting features. For many years the production from this source gradually decreased. This was largely due to the prohibition of hydraulic mining in the drainage areas of Feather, Bear, Yuba, and American rivers on account of the damage done to farming lands and to the harbor of San Francisco.

In the last ten years gold dredging has been developed to a high degree in consequence of the improvements in dredge construction and of the discovery that a large area near the mouths of the rivers flowing from the gold-bearing region of the Sierra Nevada is available for such mining. The output from the dredges in 1907 was somewhat over $5,000,000. Very sanguine predictions have been made as to the amount of land available for dredging in California and in the Rocky Mountain States, and to some degree they are justified. The fact remains, however, that the production of the Rocky Mountain States from dredging is as yet very small (about



PRODUCTION OF GOLD OF THE WORLD AND OF THE PRINCIPAL COUNTRIES FROM 1800 TO 1906.

(After E. Biedermann.)

$300,000 in 1907), and it is believed that there are no extensive areas which at all compare with those at the base of the Sierra Nevada. It is estimated by the most competent authorities that the known dredging lands in the great valley of California amount to 18,000 acres. If an average depth of 45 feet, corresponding to 72,600 cubic yards of gravel per acre, and an average content of 12 cents per cubic yard, or $8,712 per acre, be assumed, then 18,000 acres would ultimately yield $156,800,000. Up to 1905 about 700 acres had been worked. This crude estimate may be considerably off the mark, but it serves to show that a large amount of gold is contained in the dredging lands, and that the industry will be of great importance for the next quarter century at least. The total dredge production of California since 1900 is about $18,000,000.

It has been stated that the production of the placer mines, outside of the dredges, has receded pretty steadily for many years, and that this is due to the practical prohibition of hydraulic mining in the basins of the principal rivers draining into the great valley. The gold reserves in these gravels are undoubtedly very large. Were these mines allowed to operate, several million dollars per annum could undoubtedly be added to the California production. Estimates by the United States engineer officers indicate that in the basins of the Yuba, American, and Bear rivers 1,500,000,000 cubic yards of gold-bearing gravel would ultimately be available by expensive development work, consisting of tunnels, ditches, etc., the amount at present available being about 500,000,000 yards. Adding to this estimate 100,000,000 cubic yards for the Feather River and the southern rivers draining into the San Joaquin, we would have 1,600,000,000 cubic yards, much of which is poor, but which may be assumed to average 6 cents per cubic yard.

According to this rough estimate nearly $100,000,000 in gold would be available if the hydraulic mines of the central gold region were permitted to work. Siskiyou and Trinity counties now yield $600,000 per annum from their hydraulic mines. The extent of the reserves in these counties is less well known, but they are believed to be large.

No State or Territory (except Alaska) compares with California as to the probable extent of gold reserves. There is reason to believe that California can maintain a production of $15,000,000 per annum for the next fifty years, and that then it probably would not be exhausted. Ultimately, of course, the gold reserves would become smaller, as has been the experience of the European countries in which gold mining once flourished. Eventually the gravels will be worked out, the dredging ground exhausted, the quartz mines impoverished or difficult to work on account of increased expense at depth. But this is looking far into the future. What the accompanying industrial conditions will then be is beyond our ken.

ALASKA.[a]

Though recently discovered, the mineral resources of Alaska have proved to be enormous. The total production of gold has risen rapidly and almost continuously since 1890. It reached $21,400,000 in 1906, but fell to $18,500,000 in 1907, and may decline somewhat further in 1908. This recession is, however, only temporary, for it is believed that the resources in placer gold are very large. The total gold output of Alaska since 1880 is about $122,000,000. Of this about $25,000,000 was produced from quartz mines in southeastern Alaska, which annually yield about $3,000,000. The Treadwell Island group of mines is the principal factor, with an ore production of 1,400,000 tons per annum and a recovery of about $2.50 per ton. The deposit can be compared only to that of the Homestake mine in South Dakota, and, so far as known, the ore body shows no contraction or serious diminution of tenor in depth. The greatest depth now attained is 1,650 feet. Probably no obstacles to mining at far greater depths will be encountered, and the present production seems assured for many years. There are other important quartz mines in process of development.

The placer fields of Alaska are chiefly in the Yukon basin and in Seward Peninsula. Mr. A. H. Brooks has shown that in the latter region the gravels contain a total of about $300,000,000. There is probably as much in the Tanana (Fairbanks) and Yukon basins and the largest part of this will probably be extracted by dredging. With better communications and with the development of technical methods, gravels of lower grade can be worked, although the lowest grade of material possible to handle must remain very much higher than for corresponding gravels in California. While in the latter State 10 cents per cubic yard will yield a profit, 50 cents will probably be the lowest limit for some time to come in Alaska, where steam thawing must be resorted to as a rule.

The copper deposits will add a certain, though not very large, amount to the gold production and it is not impossible that workable gold-quartz mines will be discovered in Seward Peninsula and on the Yukon.

As far as visible supplies are concerned Alaska stands easily first in the United States and will yield a large annual production of gold for a long period of years.

COLORADO.

Until 1892 Colorado was of comparatively small importance as a gold producer. From three to four million dollars were contributed with great regularity from the Gilpin-Clear Creek field

[a] For a more detailed report on the Territory, see pp. 172–207.

and the San Juan region. The former field continues its production steadily with few changes; the depth attained is comparatively small and a continued yield of about $2,000,000 may be expected for an indefinite time. The San Juan region came into prominence some fifteen years ago with the development of the Telluride, Ouray, and Silverton mines and now yields annually $5,000,000 to $6,000,000. Some mines bid fair to continue for many years; others show signs of exhaustion, but the region has great possibilities and a long-continued production may be expected. In most cases reserves of "developed" or "probable" ore are not large. One prominent gold mine in this region now has reserves for two years in sight; but few have more and many have less.

The unexpected discovery and development of the Cripple Creek district in 1890 brought Colorado to the front as a gold-producing State and rapidly increased the State's output from an average of $4,000,000 to nearly $29,000,000 in 1900. In 1907 the gold production of Colorado was about $21,000,000. The new district proved extremely rich, but the largest ore bodies have now been worked out down to the depth of the lowest drainage tunnel. The quantity of ore above that tunnel has been enormous. Including 1907, Cripple Creek has produced $179,000,000. The maximum production of $18,000,000 was reached in 1900. In 1907 the output was $11,000,000. The future of Cripple Creek is largely dependent upon the character of the veins below the present tunnel level. A new tunnel 700 feet below the present drainage level is now being driven, but it will be at least two years before it will have reached the producing area. It is believed that the deposits will be less rich at greater depths, but the tunnel is likely to open many important ore bodies and its completion should be followed by an increase in the output, which may be maintained for many years. But it should be remembered that we know little about the conditions or the size of the ore shoots below the bottoms of the present shafts.

The conditions in Colorado are very different from those in California and Alaska. There are few extensive gravel beds which may be confidently predicted to yield millions of dollars. Basing an opinion as to the output of the future simply on the records of the past, one may say that the State will probably be able to maintain a production of $15,000,000 to $18,000,000 for a long period, and that the ultimate exhaustion of its lode mines is probably far distant.

NEVADA.

The gold-mining industry of Nevada has been characterized by sudden outbursts of high production followed by periods of depression. The bonanzas of gold and silver ores of the Comstock, Eureka, Tuscarora, and Pioche in the seventies were rapidly exhausted; then followed two decades from 1883 to 1903 of small gold production ranging from $1,000,000 up toward $4,000,000. The discovery of Tonopah and Goldfield brought another sudden rise in production, and in 1907 it attained $15,000,000, of which $11,000,000 was derived from the two new gold camps. The State has been very extensively prospected during the last eight years, and many new camps have been discovered, which, with improvement of methods and communications, will add their quota to its output.

To this State applies in a still higher degree what has been said about Colorado. The known reserves of ore are generally small, while their grade is high. One important mining corporation states in its report that it has reserves of about $8,000,000 in value, but this is exceptional. Other mines now producing will probably be exhausted in a short time. On the whole, however, it is likely that the aggregate output from the many mining camps already discovered will be sufficient to keep the production of the next ten years at least close to the $10,000,000 mark.

The copper mines of Ely will soon afford a steady yield of $300,000 to $500,000 per annum in gold as a by-product. Discoveries of deposits of great importance are always possible in Nevada.

CONCLUSIONS.

In the preceding paragraphs it has been shown that the reserves in gold of the United States are great, but that they can not be appraised with anything approaching exactness. Only in case of the placers is a rough estimate possible. It has been shown that the resources in placer gold are chiefly in Alaska and California. Based on present methods of working and present wages the recoverable amount of gold in these placers would perhaps approximate $1,000,000,000. The other States have also resources in placer gold, but they are of importance only in Montana, Idaho, and Oregon, and even in these States they are small compared to Alaska and California.

The placer gold won in the United States in 1907 amounted to about $24,000,000, and it is believed that this quantity can be supplied for a long succession of years. Ultimately the placers will be exhausted.

The amount of gold derived from copper ores in 1907 was only about $5,500,000, but this represents a stable and even increasing quantity which is to be relied upon at least for the next quarter century and most likely much longer. The gold derived from lead ores is much less (only about $2,100,000), and will probably slowly decrease for the next ten or twenty years.

From quartzose gold and silver ores $55,000,000 was recovered in 1907. No calculation can be made as to total reserves available, and the figures, could they be collected, would be of little use. Mines will be exhausted, but new ones are coming in. Ore shoots are worked out, but others are found. Most of the mining districts have as yet attained only a very moderate depth, and it may be said that the resources of siliceous gold ores are very far from being exhausted. Just how long they will last nobody can tell. In a general way ore deposits are more likely to decrease than increase in richness as depth is attained, and at the same time the operating costs are likely to become higher. It would seem that this ultimate decline is rather far off at the present time. Certain parts of the western country, particularly Nevada, Washington, and Idaho, still suffer from inadequate railroad communication, and each new line as a rule leads to the opening of a number of deposits which previously were unprofitable.

New discoveries are always possible and in some regions are probable. Methods of working are steadily improved.

Unless very important new discoveries are made it is thought unlikely that the production of gold in the United States will rise much above $110,000,000. Nor is it likely that it will sink below $60,000,000 within a long period of years.

The gold-bearing gravels and the dredging lands of California and other Cordilleran States have long ago passed into private hands. Only in Alaska are there any considerable amounts of such public lands left. It is believed that it would be in the highest degree inadvisable to withdraw from location any part of the placer lands of the public domain.

Regarding lode mines it must be remembered that land classed as mineral and part of the public domain may or may not be valuable. The value can, as a rule, be established only by expensive prospecting operations. To withdraw such mineral lands or to put a royalty on the product would be unwise.

WASTE.

There is comparatively little waste in the mining of gold ores. In the concentration of base ores the loss of gold is large, probably 30 per cent, but there is a relatively small amount of gold involved. In the usual combined process of amalgamation and concentration followed by cyaniding or in chlorination the loss is small; the recovery is generally about 90 per cent. In the recovery by smelting the loss of gold is extremely small and practically all of it is collected in lead or in copper matte. In electrolytic refining of copper and lead the loss is negligible.

At the same time it would be advisable to make storage of mill tailings compulsory. The reworking is sometimes profitable and can be done at little expense.

Much has been said about the loss in placer mining and in hasty operations in rich ground, as in Alaska; this is undoubtedly heavy, as attested by the repeated working of such ground. Even in better constructed plants there is some loss of fine gold, but the recovery is probably 95 per cent. In plants of the best kind, for instance hydraulic installations with undercurrents or dredges with the most improved appliances, the recovery may be considerably higher. It should be added, however, that few exact data concerning these losses are available.

CONSUMPTION.

The consumption of gold in the United States approximately equals the production; at least this appears to be true for the last thirty-five years.

In 1906, according to the Director of the Mint, the quantity of gold used in the arts, exclusive of gold coin and old material, had a value of about $29,000,000. (Total amount used in the arts, $39,000,000.) The quantity used has doubled since 1900. In 1906 gold was coined to the amount of about $79,000,000.[a] The total gold used for coinage and the arts in the United States in 1906 had thus a value of $108,000,000, or $14,000,000 more than the domestic product. The records show that a balance of $109,000,000 was imported during the same year, so that for 1906 $203,000,000 would represent the consumption of gold in the United States. The amount imported in 1907 was, however, unusually large.

For the period 1901–1905, according to Mr. Biedermann's[b] figures, the addition to the gold stock of the United States was $412,000,000, and this figure is $8,000,000 less than the domestic production for the five years. According to this the United States retained practically all of the gold produced within its territory for this time.

The total metallic stock of gold held in the United States on December 31, 1906, was, according to the estimate of the Director of the Mint, about $1,600,000,000. The production of the United States since 1873 is $1,650,000,000.

The total stock of gold coins in the world in 1905 was $8,050,000,000. Adding to this $2,000,000,000 as the probable amount used in the arts, we have a total of $10,000,000,000. Against this the total gold production of the world since 1860, according to the Director of the Mint, is $7,652,000,000.

The gold production of the world for the five-year period, 1901–1905, amounts to about $1,688,000,000.[b] This has ultimately been divided between the nations as follows: United States, $412,000,000; France, $378,000,000; Germany, $242,000,000; India, $177,000,000; Great Britain and Austria, each $112,000,000.

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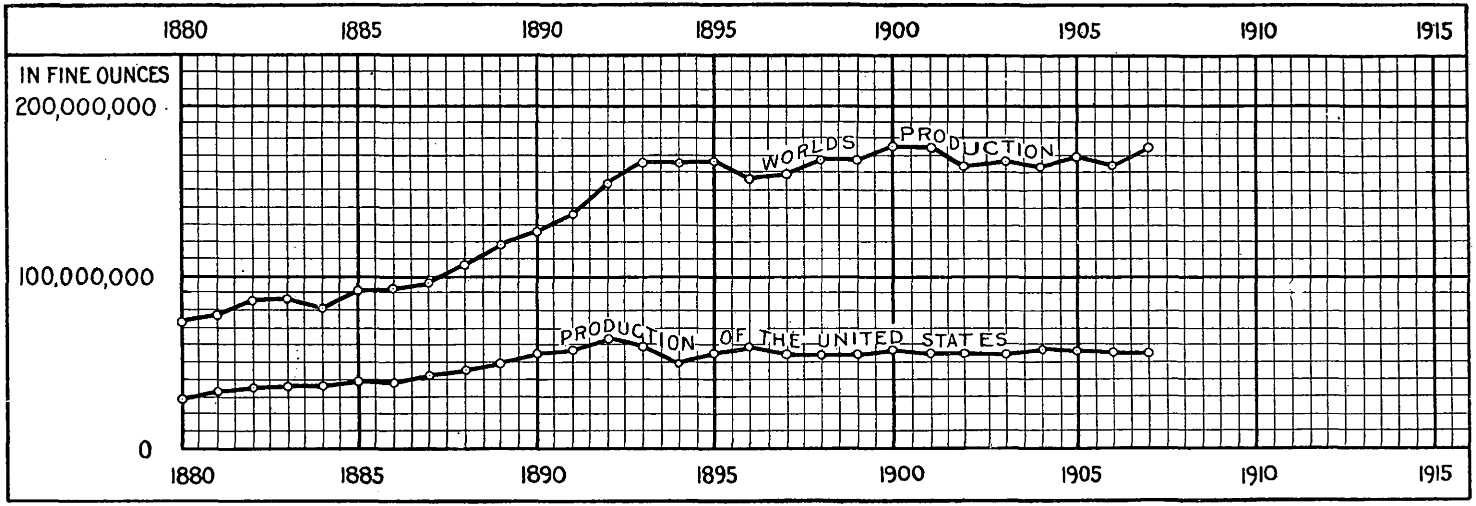
[a] Probably $6,000,000 of this consisted of mutilated domestic coins and scrap.

[b] Biedermann, E., Die Statistik der Edelmetalle, etc.; Zeitschr. Berg, Hütten u. Salinenwesen, Bd. 56, Heft 1, Berlin, 1908.



PRODUCTION OF SILVER OF THE WORLD AND OF THE UNITED STATES FROM 1880 TO 1907.

The flow of gold to India and Egypt has often been emphasized in the press. No doubt such importations are manufactured into jewelry or are hoarded and are permanently lost to commerce and industry. The above figures will show, however, that such hoarding has not caused the great demand for gold during recent years. The real cause is the heavy absorption of the metal by the commercial nations in order to fortify their monetary position. The introduction of the gold standard has forced those great nations to create large gold reserves. This process has been going on for the last twenty years, but from now on the demand for gold for this purpose will probably slacken.

SILVER.

PRODUCTION OF THE UNITED STATES.

The silver production of the United States became of importance about 1860 and increased rapidly up to 1892, when it attained 63,500,000 fine ounces. The decline in the price had begun in 1875, and in the year of maximum output the price had fallen to 88 cents per fine ounce. Since 1892 the yield of silver has remained practically constant, averaging about 55,000,000 ounces. In 1907 it was 56,500,000 ounces, but the present year will witness a considerable decline. The lowest price of silver was about 47 cents, in 1902. The price rose to 70 cents in 1907, but has again declined to 50 cents, in October, 1908. The general result has been that a great number of mines which extracted silver ores have closed down, but the compensating factor that an increasing quantity has been obtained as a by-product from lead and copper ores has kept the output steady. The lower line in the diagram shows the course of the production of the metal in the United States.

PRODUCTION OF THE WORLD.

The world's production of silver was 92,000,000 ounces in 1885, and about 178,000,000 ounces in 1907. The upper line in the diagram represents the world's production in the same time, and it well illustrates its constancy. (See Pl. VIII.) The United States and Mexico are the most important contributors to the production of the world, the supply from each source being from 55,000,000 to 65,000,000 ounces. The rehabilitation of the mining industry of Mexico, which has taken place in the last twenty years, has gradually increased its output to more than double that of 1885. The remaining third of the world's production is mainly derived from New South Wales, Germany, Peru, and Bolivia. In many countries the output of silver is receding, owing to low price and difficulty of competing with the United States. To offset this, the silver output of Canada has lately been increasing at a rapid rate, and in 1907 attained nearly 20,000,000 ounces.

RESOURCES OF THE UNITED STATES.

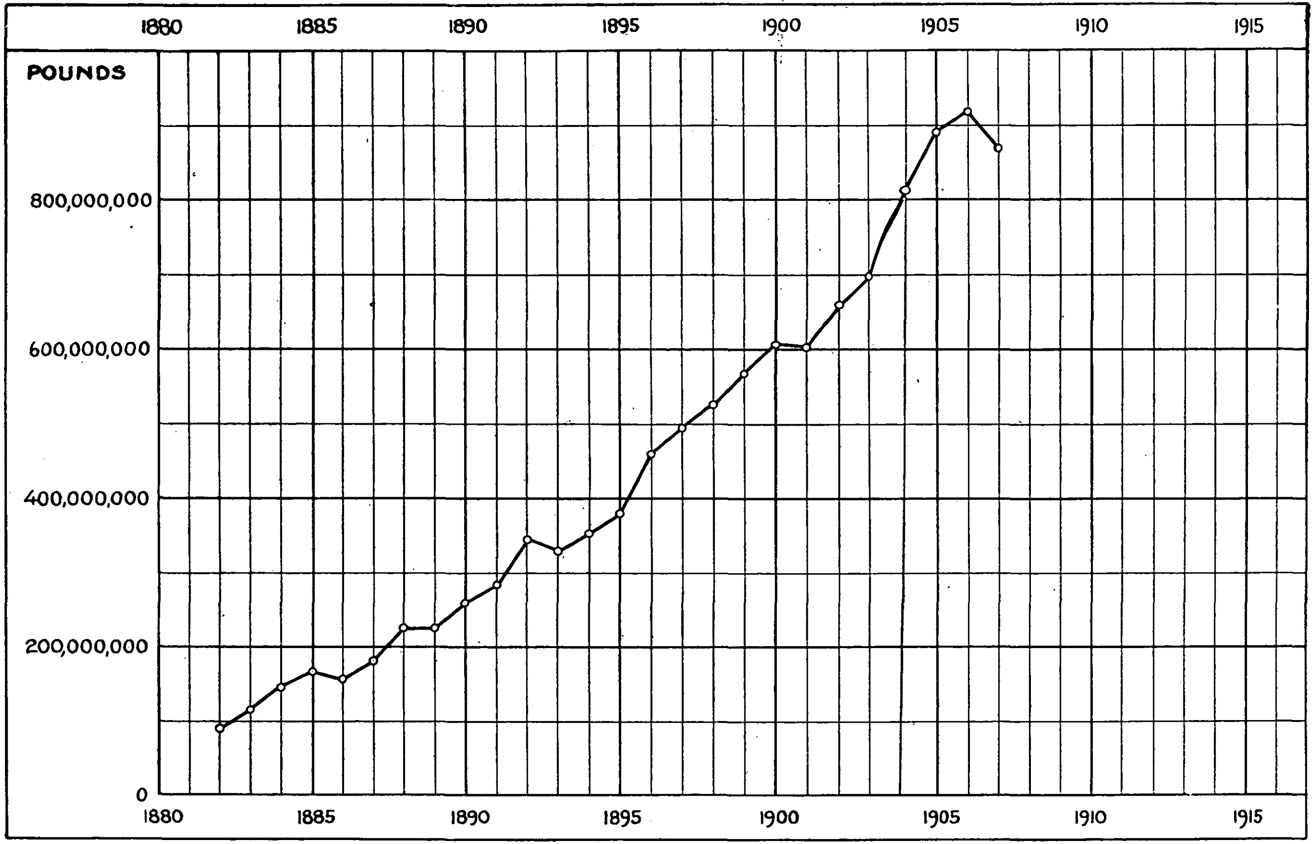
The silver-producing States had in 1907 the following rank: Colorado, Montana, and Utah, each producing slightly over 11,000,000 fine ounces; Nevada and Idaho, each yielding about 8,000,000 ounces; Arizona, 3,000,000 ounces; and California, 1,500,000 ounces. None of the remaining States produced over 600,000 ounces.

An analysis of the statistics of 1906 is published in Bulletin 340 of the United States Geological Survey. From this it appears that the total output, disregarding the small amount of silver obtained from placer gold, was derived as follows: From lead, copper, and zinc ores, 40,100,000 fine ounces; from quartzose gold and silver ores, 16,500,000 ounces. A large proportion of the base-metal ores contained only a small amount of silver, which might be properly regarded as a by-product. Quartzose gold ores also contain silver which is recovered as a by-product and from this source 4,000,000 ounces were obtained in 1906, making one-quarter of the total from quartzose ores.

Looking at the question from another standpoint, it was found that from ores which carry predominating silver values, and which thus may be classed as silver ores, 19,500,000 fine ounces of silver were obtained. This is somewhat more than one-third of the total output of 56,500,000 ounces. It must be taken into consideration, however, that at least one-half of these ores could be profitably mined only because other metals besides silver were present. Only 1,500,000 ounces were obtained from ores containing no other recoverable metals.

From these data the present small importance of silver mining as a distinct and separate industry is clearly perceived. The pure silver ores are not scarce, but at the present price of the metal they can not be profitably treated unless containing at least about 20 ounces per ton. The lead ores of the Rocky Mountain region are as a rule richer in silver than the copper ores. In the lead ores of the Mississippi Valley silver is either absent or contained in extremely small quantities. Should the quantity of lead ores mined in Colorado and Utah gradually diminish, which seems probable, a corresponding diminution of the silver supply would follow. On the other hand, copper will probably for many years be mined on an increasing scale, and although the copper ores are poor in silver, the great tonnage handled will add much silver to our annual output and compensate for the possible loss from the decrease in the supply of lead ores. The zinc ores do not contain much silver; those of southwestern Missouri are free from silver, and the Rocky Mountain ores rarely contain more than a few ounces per ton.

From all this it is evident that the present supply of silver is assured as long as the mining of lead and copper ores, as well as of quartzose gold ores, continues on the present scale. Should there ever



PRODUCTION OF COPPER IN THE UNITED STATES FROM 1882 TO 1907.

be a scarcity of silver, with accompanying rising price, the Rocky Mountain region beyond doubt contains a large supply of quartzose low-grade silver ores which could be profitably extracted with silver above 70 or 80 cents per ounce.

CONSUMPTION.

The United States consumes only a part of the silver produced. The domestic consumption is divided between coinage and industrial uses for the manufactures and arts. The demands for the latter use have doubled since 1898, and at present the amount consumed is 20,000,000 ounces, of which about 4,000,000 ounces represent old material remelted. For coinage the mints consume variable amounts ranging, during the last ten years, from 4,500,000 ounces to 23,000,000 ounces. In 1906, 7,700,000 fine ounces were coined. The total domestic consumption of the yearly product of the mines may be placed at 25,000,000 ounces. The remainder, about 32,000,000 ounces, is exported As is well known, the larger part of the export is taken by India and China. The demand by India is in the aggregate an enormous sum and is increasing at a rapid rate. For 1906–7 the total imports of silver by India were over 118,000,000 ounces, an increase of 34,000,000 ounces over 1905–6. On the other hand, the generally much smaller demand from China fell off, and during 1906 that country actually exported silver. The larger part of the silver which goes to India is, as well known, permanently lost to our industrial world by hoarding. Since the Indian government has succeeded in establishing the permanent value of the rupee at 16 pence (on basis of 1:21.85) it is likely that the decline in price of silver will be checked, but the supply appears to be so great that a vigorous recovery can hardly be expected.

COPPER.[a]

PRODUCTION OF THE UNITED STATES.

The copper-mining industry of the United States has developed at a rapid rate. In 1888 the production was 226,000,000 pounds of the metal. After eight years, in 1896, it had doubled. After ten years again, in 1906, it had nearly quadrupled, attaining almost 918,000,000 pounds. Reactionary tendencies developed in 1907, but the output of 1908 attained 943,000,000 pounds.

It is impossible to predict the final character of the curve of production (Pl. IX), but if we draw a straight line from the point on the diagram representing the production of 1883 to that of 1908, we shall with some probability have the trend of the production for future years. It is altogether improbable that the increase will continue at an increasing rate; more likely the rate will gradually diminish; a straight line will probably express its trend for the next ten years, at

[a] Prepared with the assistance of Mr. L. C. Graton, of the U. S. Geological Survey.

least. On this basis the production would be about 900,000,000 pounds in 1910, and 1,160,000,000 pounds in 1920. The following table will give a good idea of the growth of the industry since 1845. It shows that the rate of increase during the present decade is considerably smaller than it was during the decades 1881–1890 and 1891–1900:

Magnitude and growth of copper production in the United States from 1845 to 1907, inclusive.

Year.	Production.	Increase.		Average annual increase by decades.	
	Pounds.	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*
1845	224,000				
1846	336,000	112,000	50.0		
1847	672,000	336,000	100.0		
1848	1,122,000	450,000	67.0	242,400	50.0
1849	1,568,000	426,000	40.0		
1850	1,456,000	*a* 112,000	*a* 7.1		
1851	2,016,000	560,000	23.1		
1852	2,464,000	448,000	22.2		
1853	4,480,000	2,016,000	81.8		
1854	4,990,000	510,000	12.5		
1855	6,720,000	1,730,000	33.3	1,467,200	27.0
1856	8,960,000	2,240,000	33.3		
1857	10,752,000	1,792,000	20.0		
1858	12,320,000	1,568,000	14.6		
1859	14,112,000	1,792,000	14.5		
1860	16,128,000	2,016,000	14.3		
1861	16,800,000	672,000	4.1		
1862	21,160,000	4,360,000	20.0		
1863	19,040,000	*a* 2,120,000	*a* 5.5		
1864	17,920,000	*a* 1,120,000	*a* 5.9		
1865	19,040,000	1,120,000	6.3	1,209,600	6.1
1866	19,936,000	896,000	4.7		
1867	22,400,000	2,464,000	12.3		
1868	25,984,000	3,584,000	16.0		
1869	28,000,000	2,016,000	7.7		
1870	28,224,000	224,000	1.0		
1871	29,120,000	896,000	3.2		
1872	28,000,000	*a* 1,120,000	*a* 3.8		
1873	34,720,000	6,720,000	24.0		
1874	39,200,000	4,480,000	12.9		
1875	40,320,000	1,120,000	2.9	3,225,600	7.2
1876	42,560,000	2,240,000	5.6		
1877	47,040,000	4,480,000	10.5		
1878	48,160,000	1,120,000	2.4		
1879	51,520,000	3,360,000	7.0		
1880	60,480,000	8,960,000	17.4		
1881	71,680,000	11,200,000	18.6		
1882	90,646,232	8,966,232	12.5		
1883	115,526,053	24,886,221	27.4		
1884	144,946,653	29,420,600	25.5		
1885	165,875,766	20,929,113	14.4	18,930,349	14.8
1886	156,735,381	*a* 9,140,385	*a* 5.5		
1887	180,920,524	24,185,143	15.4		
1888	226,361,466	45,440,942	25.1		
1889	226,775,962	414,496	.2		
1890	259,763,092	32,987,130	14.5		
1891	284,121,764	24,358,672	9.4		
1892	344,998,679	60,876,915	21.5		
1893	329,354,398	*a* 15,644,281	*a* 4.8		
1894	354,188,374	24,833,976	7.5		
1895	380,613,404	26,425,030	7.4		
1896	460,061,430	79,448,026	20.9	34,635,407	9.1
1897	494,078,274	34,016,844	7.4		
1898	526,512,987	32,434,713	6.6		
1899	568,666,921	42,153,934	8.0		
1900	606,117,166	37,450,245	6.6		
1901	602,072,519	*a* 4,044,647	*a* 0.7		
1902	659,508,644	57,436,125	9.5		
1903	698,044,517	38,535,873	5.8		
1904	812,537,267	114,492,750	16.4	37,554,189	5.5
1905	888,784,267	76,247,000	9.4		
1906	917,805,682	29,021,415	3.3		
1907	868,996,491	*a* 48,809,191	*a* 5.3		
Total production, 1845–1907	12,163,637,913				
Average annual increase, 1846–1907		13,880,213	15.0		
Average annual increase, 1846–1881		2,034,333	17.2		
Average annual increase, 1882–1907		30,282,201	9.9		

a Decrease.

PRODUCTION OF THE WORLD.

The world's production of copper has also increased rapidly, but not at the rate attained by the United States. From 274,000 metric tons in 1890 it has grown to 711,000 tons in 1907. To this amount the United States contributed, respectively, 118,000 and 386,000 metric tons. The paramount importance of this country is easily perceived.

The world's production, outside of that of the United States, increased as follows:

	Metric tons.
1890	156,000
1895	165,000
1897	182,000
1900	219,000
1905	297,000
1907	325,000

From this it will be seen that the increase was slow from 1890 to 1895, and that it then began to mount rapidly, doubling in the twelve years from 1895 to 1907.

No single country compares in importance with the United States. The supply from the Rio Tinto mines in Spain and Portugal is almost constant at 50,000 metric tons per annum; that of Germany and Chile likewise, with, respectively, 20,000 and 27,000 tons. Australia, Canada, Mexico, Japan, and Russia have shown rapid growth in the copper industry; among these Japan leads with an output of 49,000 metric tons in 1907. For the next few years increased production may confidently be expected from Canada, Mexico, and Russia. Copper deposits of enormous extent are reported to have been discovered in central Africa. Their product is not likely, however, to compete with other sources for several years.

RESOURCES OF THE UNITED STATES.

For many years the bulk of the copper production has been divided between Michigan, Montana, and Arizona. In each of these States the increase has been rapid and continuous since 1880, but for a series of years, beginning with 1891, Montana far exceeded the other two States. In 1895, for instance, Montana produced 50 per cent; Michigan, 34 per cent; and Arizona, 12.6 per cent of the total output. During the last few years there has been a tendency to equalization, caused by the rapid advance of Arizona. In 1907, of a total of 869,000,000 pounds, Arizona yielded 257,000,000; Montana, 224,000,000; and Michigan, 219,000,000 pounds. Utah comes next with a production of 66,000,000 pounds. California yielded 34,000,000 pounds; Tennessee, 20,000,000 pounds; Colorado, 14,000,000 pounds; New Mexico and Idaho each, 10,000,000 pounds; Alaska, 7,000,000 pounds; Wyoming, 3,000,000 pounds; and Nevada, 2,000,000 pounds. These 12 States are the only ones which will have to be considered in more detail. The less important will first be disposed of.

COLORADO.

Colorado can be dismissed in a few words because the copper is largely recovered as a by-product from many mines with mixed ores, chiefly, in fact, from the Leadville mines. The State has no important copper mines and it is not likely that its production will exceed the figure of 1907, when special incentive to the recovery of this metal was given by abnormally high metal prices.

IDAHO.

Idaho has three copper districts of some importance—the Cœur d'Alene, the White Knob, and the Seven Devils. With copper prices at 13 cents the last two districts will probably not be able to attain a large yield. At present the greatest part of the production comes from the Snowstorm mine in the Cœur d'Alene district. With copper at 15 cents, or higher, the reserves of the State will be materially augmented and the present production could probably be increased.

WYOMING.

The State of Wyoming produces copper from the Encampment district, near the Colorado line. The deposits are fairly large and there is probably a considerable amount of low-grade ore in the district. Low-grade copper deposits are known to exist in Albany, Fremont, and Natrona counties. The State will never rank among the greatest producers in the country, but may be able to maintain a production of a few million pounds per annum.

NEW MEXICO.

New Mexico possesses large bodies of low-grade copper ores in the Burro Mountains and at Santa Rita. Exact figures can not be given, but with copper prices at 15 cents the Territory will probably be able to maintain its present output (10,000,000 pounds in 1907) for a long period of years. Many of the other mining districts, especially the Mogollon and the Organ, will continue to contribute to the total output. The copper-bearing sandstones of upper Carboniferous to Lower Cretaceous age are developed in New Mexico upon an enormous scale. They are present in the Zuni, the Nacimiento, the Mora, the Oscura, and many other ranges. Past experience has shown that with copper at 13, 15, or even 20 cents, these extensive deposits can not be profitably worked, except on a small scale for selected rich ores; but with prices above 20 cents they should come into the range of probable resources.

ALASKA.

The Territory of Alaska contains at least three copper districts of importance, the Kasaan Peninsula, Prince William Sound, and the Copper River region. From the first and second districts an output of 7,000,000 pounds was obtained in 1907. The deposits are irregular. The ores of the first district are of low grade but easily smelted. At copper prices of 13 cents the outlook is doubtful, but at a higher rate the peninsula may yield a considerable amount for a number of years. The deposits on Prince William Sound are considered promising, but are too little developed to allow a judgment as to future possibilities. Probably they will furnish a fair amount of copper. The Copper River deposits are likewise as yet in the prospect stage, but may in time develop into an important copper-mining district. The most promising property is at present the Bonanza mine, a large body of high-grade chalcocite ore. No data are as yet available as to its continuation in depth.

TENNESSEE.

At Ducktown, Tenn., the Tennessee Copper Company and the Ducktown Sulphur, Copper, and Iron Company are producing an aggregate amount of 18,000,000 to 20,000,000 pounds of copper per annum. The reserves of ore are believed to be sufficient for at least ten years. It is said that the former company has now developed and produced ore to the extent of 3,300,000 tons. About 389,000 tons of ore were mined by this company in 1907.

We now come to a consideration of the States which at present are of paramount importance in the production of copper. They are Michigan, Arizona, Montana, Utah, Nevada, and California.

MICHIGAN.

Michigan, which up to the present time has been the largest contributor of all the States to the total copper output of this country, began production in 1845 and has been steadily and increasingly productive ever since. The output in 1907 was over 219,000,000 pounds. The entire production has been drawn from the Lake Superior copper district of the northern peninsula, and the productive area is a belt 1 or 2 miles wide by about 70 miles long. Developments are more extensive than in any other copper district. The grade of the ores has steadily declined and now averages only about 1.1 per cent recovered. Costs of operations are extremely low, however, and the greater part of the present output can be maintained under the current copper market. The tonnage of ore that is reasonably assured is enormous and probably exceeds that in any other district; it is now being depleted at the rate of almost 10,000,000 tons annually.

One company alone estimates 20,000,000 to 25,000,000 tons remaining in one lode (the "Calumet" conglomerate) in its ground that has been worked since the sixties of last century. Another lode (the Kearsarge) is being mined for 12 miles along its strike almost without break, and to depths on the incline ranging down to about 5,000 feet. A third very important lode (the Baltic) is being found much more extensive than formerly known, and, like the Kearsarge, promises to yield an enormous output before exhaustion. Two other lodes (the Osceola and Pewabic) are of much importance and may be safely counted on for large production for many years. Several of the smaller producing lodes will long continue to contribute to the State's supply, and some of the extensive development in the northern end of the district is likely to bring out important resources.

The conglomerate ores, which so far have yielded more than half the total output and are decidedly richer than the amygdaloid ores, will probably cease to be productive, at the present rate of working and under normal prices, at the end of fifteen years—twenty at most. But the amygdaloid ores, which are much more cheaply worked and in this way offset their lower yield, are able to maintain the district as one of the great copper regions of the world for many years to come. The deepest workings have now attained a vertical depth of practically one mile, and as the workings are extended farther down, the increasing cost of operation and the decreasing grade of ore will ultimately make mining unprofitable. While this condition seems not far in the future at certain local points, its effect on the general output of the district will, to judge from present tendencies, be felt at a very remote time.

Copper is known to occur for many miles beyond the southwestern end of the productive belt, but the development of important resources there is as yet problematical. It is probable that at best that section can achieve important output only under higher prices than can be reasonably expected for many years.

ARIZONA.

The foundation of the present production of Arizona, which in 1907 was about 257,000,000 pounds, was laid in 1873, when mining began in the Morenci district. Within a few years the Bisbee district became a producer and the ores of the old silver district at Globe became chiefly valuable for copper. Shortly afterward the United Verde mine at Jerome became an important producer. The production of these four districts increased steadily and rapidly, and in 1907 they produced jointly over 240,000,000 pounds, or more than the total yield of any other State. While there are a large number of other producing districts in the Territory, of which two or three are of decided promise, these four principal centers of production must be chiefly relied on for many years if Arizona is to maintain her output.

The Bisbee district produced about 110,000,000 pounds in 1906, and practically all of it came from ores of relatively high grade. Most of the output was from secondary or enriched ores, and was produced at a cost low enough to maintain the district as an important producer with prices decidedly lower than at present. The principal companies are known to have good reserves blocked out, but figures as to tonnage and tenor are not available. There is a fair outlook for adding laterally to the productive area. The lowest workings are about 1,600 feet deep, and the bodies of good grade encountered at that depth are an encouraging indication of the future possibilities of the camp.

The high-grade ores of the Morenci district have been largely exhausted, and for a number of years the chief source of production has been the comparatively low-grade concentrating ores formed by secondary enrichment. The production in 1907 was about 63,000,000 pounds. A large tonnage is still doubtless available for extraction, but at a depth which only in a few places exceeds 400 feet the workable ores give way to the original pyritic deposits that are of too low grade to be profitably worked under any conditions that can at present be reasonably forecast. The ground that is possibly copper bearing has not yet been entirely prospected, and during the past three years of good prices the principal operators have conserved the better-grade ores. But it seems probable that the district has about reached its climax in annual output, and that a sustained period of low prices might cause the production to decline sharply.

At Bisbee and at Morenci the precious metals occurring with the copper are not sufficiently plentiful to have appreciable effect on conditions of production.

The Globe ores likewise were formerly of high grade, but the district, which produced 35,000,000 pounds in 1907, is relying more and more on its medium and low grade ores. The bulk of the present output is from enriched ore. Lean pyritic ore has been reached at a depth of about 800 feet, but the secondary ore of workable grade has been developed in places to the present maximum depth of about 1,200 feet. There is reason to believe that some of the underlying sulphide ore may be profitably extracted, but as a source of important contribution to the copper supply this is very uncertain. Recently the Miami Copper Company has developed a very important low-grade deposit of the well-known type, consisting of disseminated secondary sulphides. The company estimates 4,200,000 tons of 2.9 per cent ore developed and 2,200,000 tons of probable ore in addition, with good prospect of increasing this tonnage. They estimate that in all probability a total of at least 250,000,000 pounds of copper can be taken from the mine as at present developed at a cost of 9 cents per pound. Production from this property is expected to begin in the near future. In the vicinity of Globe there is without doubt a large tonnage of ore, partly of good grade, not as yet altogether systematically developed. Promised improvement in local transportation and bettered metallurgical conditions resulting from increase of sulphide ores produced in the district will almost certainly be followed by increased production from this outlying territory, but the magnitude and persistence of this supply can not now be foretold.

The Jerome district, in Yavapai County, produced 33,000,000 pounds of copper in 1907. As in former years, nearly all this came from the United Verde mine. The ore body is a great lens of pyrite and chalcopyrite in schists and has been opened by workings to the 1,000-foot level, beyond which depth the ore is reported to continue. There is undoubtedly a large tonnage yet to be extracted above this level. Gold and silver are present to the extent of about 1.4 cents per pound of copper, and the copper percentage is high, the ore ranking with the Bisbee ores as the richest now mined on a large scale in the United States. Prospecting in the surrounding region has not as yet disclosed any other deposits of importance.

At the Silver Bell district, in Pima County, important developments have been made and improvements are nearly completed to largely increase the production of 1907, which was over 5,000,000 pounds. Contact-metamorphic sulphide ores of both smelting and concentrating grade have been opened and the tonnage exposed is reported to be large. In the Mineral Creek district of Pinal County the Ray Consolidated Copper Company has opened a disseminated chalcocite body in porphyry, and estimates indicate that about 3,000,000 tons of about 2.4 per cent tenor have been already developed and can be profitably worked with copper selling at 12 cents. A large tonnage of low-grade garnet-chalcopyrite ore is reported as existing in the Saddle Mountain region, in Gila County, but it is not certain that it can be worked at the present metal market. A large quantity of low-grade ore consisting of copper minerals disseminated in sedimentary rocks is known in the Grand Canyon region, but development has been slight and no generally satisfactory method of reduction has yet been found for application at recent prices of copper.

These four regions have not yet been studied by members of the Geological Survey, and further definite information is not available.

A few million pounds of copper are produced annually in Arizona incidental to the recovery of precious metals. This will doubtless continue, and the probability is that the quantity will increase somewhat. While this source of supply will be relatively independent of the price of copper, it probably can never be of much importance.

The prospect of discovering new important copper fields in Arizona is perhaps brighter than in any other State or Territory.

MONTANA.

The importance of Montana as a copper-producing State began in 1880 with the advent of railroad transportation to Butte, the only large copper district of the State. Production increased with great rapidity, and in 1887 the district was the most productive in the world. It has held that rank almost steadily to the present time, as Montana led in the production of copper until 1907, when it was surpassed in this respect by Arizona. The production of the State in that year was about 224,000,000 pounds, nearly all of which was derived from Butte. The ore bodies of Butte are secondarily enriched portions of pyritic replacements and impregnations of zones of crushed granitic rock. In the early years the ores were of extremely high copper content and carried much silver. Now the greater part of the production is from rather low-grade concentrating ores, and the recovery from all ores is but little over 3 per cent copper. The yield of precious metals is more than 2 cents per pound of copper. The principal output is from a very small territory, and prospecting in the outlying ground during the last few years has failed, in most cases, to give encouraging results. A large tonnage of ore is undoubtedly still available for extraction, but lean pyritic material has been encountered in a number of places at about the same depth (the 1,600-foot level of certain mines) and most of the good ore bodies that occur at greater depths, down to 2,600 feet, are probably to be regarded as localizations of enrichment along certain easily permeable channels. The cost of producing copper is high and the output at the rate of 1905 and 1906, or even of 1907, probably can not be maintained for a long period on copper at 13 cents per pound.

UTAH.

The production of Utah has increased greatly during the last few years. In 1903 the output was approximately 30,000,000 pounds, while in 1906 it had attained 66,000,000 pounds, with prospect of still further increase. The Utah copper is mainly derived from the Bingham district, though smaller quantities are obtained from the Tintic and Frisco districts. All these ores yield also much gold and silver, and their extraction is therefore to a certain extent independent of the price of copper. A production of about 50,000,000 pounds could undoubtedly have been maintained for a series of years, as new reserves were constantly discovered. The recent discovery and utilization of the low-grade Bingham porphyry ores, probably the largest single body of copper ore known in the United States, will, however, advance Utah still further in the rank of the copper-producing States. The two largest companies which treat this ore estimate the aggregate reserves of ore blocked out or partially developed at 120,000,000 tons, which, provided that all of this ore can be extracted, should yield a very large quantity of copper, besides a considerable amount of gold and silver. The yield thus far is somewhat below 2 per cent copper. The copper can be produced cheaply, it is claimed at 8 cents per pound. The tonnage to be treated per day in the plants of the Utah Copper Company and the Boston Consolidated Copper Company is over 9,000 tons, or 3,150,000 tons per annum. At this rate the ores would last about thirty-eight years. In addition a large amount of ore of somewhat lower but probably workable grade is partly developed.

NEVADA.

Until recently Nevada was of little importance as a copper-producing State, but the development of the Ely and Mason Valley districts have materially changed the outlook. At Ely low-grade but enormously large copper deposits have been opened and will begin production in 1908. The three companies working at Ely, the Nevada Consolidated Copper Company, the Cumberland-Ely Mining Company, and the Giroux Consolidated Mines Company, report an aggregate of about 28,000,000 tons of developed and probable ore containing about 2 per cent copper with some gold and silver. The mills erected will have a total capacity of 4,500 tons per day, or 1,500,000 tons per annum. The proved reserves would therefore last about nineteen years. The total cost of mining and reduction will, it is believed, be low; it is claimed less than 10 cents per pound of copper. It is thought that the output of the Nevada Consolidated will be at the rate of 24,000,000 pounds per annum. In the Mason Valley district near Yerington important bodies of ore have also been opened and will probably soon contribute to the output of Nevada.

CALIFORNIA.

The copper production in California began in Calaveras County about forty years ago, but the industry there soon declined and it was not until 1897, when the Shasta County mines began copper production, that the output of this State became important. The production in 1907 was over 33,000,000 pounds.

The Shasta County copper region, which in 1907 produced about 28,000,000 pounds, embraces four districts within an area about 6 by 20 miles. Rich copper-silver ores were first worked at some of the mines, but these have been exhausted, and practically the whole output is at present derived by smelting massive pyritic ores, which yield on the average about 3.6 per cent copper and nearly 3 cents in gold and silver per pound of copper. The ore bodies are large replacement bodies, mostly in porphyry, and in most cases are flat-lying lenses; in a few cases the ore bodies are more nearly vertical. A very large tonnage is now blocked out and in process of extraction. One company has several million tons practically developed, and four other companies have proved up large reserves. One of the largest bodies has been practically worked out and the limits of most of the others are now known. Additional deposits may be discovered from time to time, for the region has not been thoroughly prospected, but the probability is that the best deposits existing are already known. Some of the mines probably have ore of too low grade to be continuously worked with profit under the current prices for copper, and others are dependent for present operation on the simultaneous production of sulphuric acid from the ores. Under favorable metal prices the production of the region is likely to increase rapidly and then after a number of years to decline sharply.

The only other copper-producing district of any importance in California is in Calaveras County, where sulphide ore of good grade is found in schist. The production has varied greatly from year to year. In 1907 it was somewhat over 4,000,000 pounds. Details as to the probable future of this region are not available, but the outlook is generally considered good.

There is a long stretch of country in the western foothills of the Sierra Nevada where copper is known to occur mostly as lenticular sulphide bodies in schist or slate. Small production has been made from time to time. At most points developments are meager and the future is unknown, but there is reason to believe that with proper application of capital, improved transportation, and good copper prices, this district might make a considerable output. At the Dairy Farm mine, in Placer County, on this belt, a large body of sulphide ore has been blocked out and extraction will probably begin in the near future. The ore is not of high grade; and no figures regarding the extent of the developed ore are available.

Small production comes from Inyo and San Bernardino counties, in the southern part of the State, but developments as yet do not warrant relying on that region for an important copper supply.

CONCLUSIONS.

The visible reserves of copper ore in the United States are much larger than those of lead ore. Moreover, they are very much larger now, at the maximum of production, than they have ever been before. And yet, upon perusing the preceding notes it is evident that few companies have reserves for as much as ten years and that only in one case are they believed to be sufficient for thirty-eight years. On its face this condition seems discouraging, at least when we compare it with the enormous reserves established in the investigation of the coal-mining industry. As has been explained in the general part of this discussion, copper deposits differ so completely in their occurrence from coal beds that known reserves like those of coal can not be expected. Each year will, however, surely find extensions of reserves added to those already discovered and large new deposits of low-grade copper ores will also undoubtedly be opened. These possibilities are well illustrated by the discovery within the last two years of a 7,000,000-ton ore body near the old camp of Globe, Ariz., which one might reasonably suppose to be well prospected.

All these data of available reserves are based on copper at about 13 cents per pound. A large part of them would prove unprofitable to extract should the value of the metal sink much below that figure. Should copper increase to 15 or 20 cents per pound the reserves of many mines would unquestionably be vastly increased. Should it go above 20 cents per pound, still more extensive reserves would be available in the cupriferous sandstones of the Southwest. These conclusions, again, are based on present methods of working and recovery. Should further great improvements be made in these processes the limits indicated by the prices might be materially altered.

The copper resources of the United States are believed to be large enough to respond for a number of years to a demand increasing at the rate of 30,000,000 pounds per annum. It is to be anticipated that should this demand continue for a long period the scarcity of ore would ultimately be felt and result in a rising price for the metal. This again would undoubtedly cause the substitution of other metals, like aluminum, for copper whenever possible.

All these considerations have left the foreign supply out of the question. If recent reports are correct, central Africa contains enough copper to supply the world for years to come.

The whole problem of the copper supply contains so many unknown quantities that final and definite judgment is impossible. In the last analysis, however, it comes down to the question whether it is better for a country to reserve its copper for the future, when its value is an unknown quantity, or to extract the ore at as rapid a rate as possible when profit is assured. It is believed that the latter method is the best, if at the same time avoidable waste is prevented.

CONSUMPTION.

Only a part of the copper produced is consumed in the United States; exports have been maintained on an increasing scale for the last thirty years. At the present time some, but not much, copper ore is imported to our smelters. On the other hand, there is a large output of foreign raw copper which is refined in the United States. In 1907 the total foreign copper refined in this country amounted to 248,000,000 pounds, or one-third of the domestic production of refined new copper, which for the same year was 784,000,000 pounds.

There is no duty on copper or copper ores to interfere with the natural operations of supply and demand. The copper industry has developed in a natural and free manner and no single concern has yet obtained control of the market.

The domestic consumption has increased from about 350,000,000 pounds in 1900 to 685,000,000 pounds in 1906. In 1907 it had decreased to 485,000,000 pounds. To this should be added the consumption of copper recovered from scrap, which was about 60,000,000 pounds in 1907, making a total consumption of about 545,000,000 pounds.

The uses are principally for wire or other electrical purposes, brass, castings, and sheet copper. There is no such great amount permanently lost as in lead and zinc, and a large quantity of scrap will be available with increased production and consumption.

WASTE.

It is not believed that the waste in the mining of copper ore is excessive. Ores too poor to extract at prevailing prices are, of course, left in the mine. But with present methods of extraction, whether timbering, filling, caving, or steam-shovel methods, there is little profitable ore left in the mines.

Much larger are the losses in concentration. The principal valuable mineral in the concentrating ores is chalcocite, which is easily slimed; the loss may be 30 per cent of the metal contained, and it is not always easy to avoid it. Storage of tailings should be enforced, even though in many cases the grade of the ore is so low that there is little present probability of utilization. The waste in copper smelting is not large and the slags are easily available for resmelting; at many reduction works old slags are used as a fluxing material.

LEAD.[a]

PRODUCTION OF THE UNITED STATES.

The diagram (Pl. X) shows graphically the annual production of lead in the United States for the last twenty-eight years. From 129,000 short tons, in 1885, the production increased at a moderate rate to 1895, when it was 170,000 tons, an average increase of about 3,700 tons per annum for eleven years. The second epoch, from 1895 to 1907, presents radically different conditions. The output rose rapidly and steadily, except for small setbacks in 1899 and 1905, at an average increase of almost 15,000 tons per annum, or about four times as rapidly as in the previous eleven years. In 1895 the total was 170,000 tons; in 1907, 365,000 tons. The increase since 1895 has been at an almost even rate, by average, as clearly indicated on the diagram. Should this rate of increase be maintained, the production of 1910 would be 410,000 tons, and that of 1920, 560,000 to 580,000 tons.

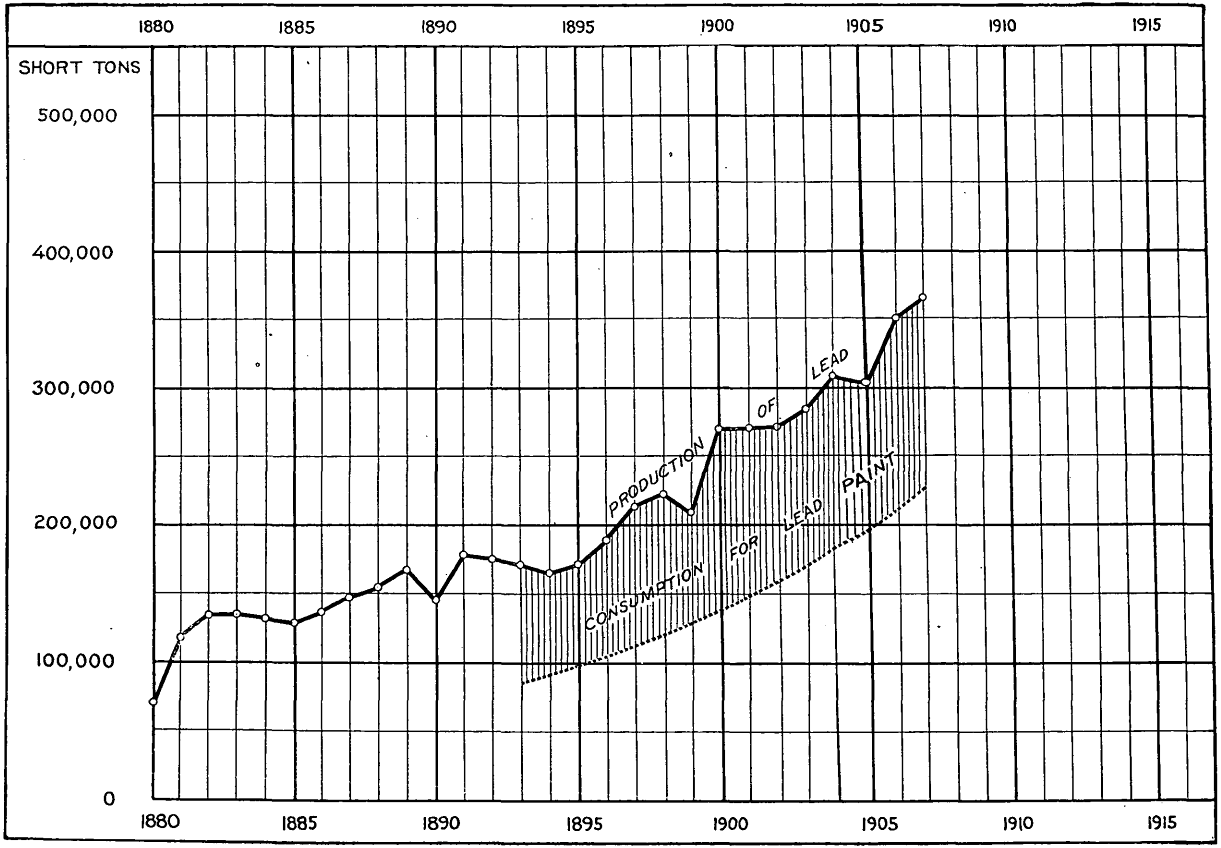
PRODUCTION OF THE WORLD.

In 1907 the world's production of lead was about 965,000 metric tons, while that of the United States amounted to 317,500 metric tons, or about one-third of the whole.

The world's production of lead has not advanced at so rapid a rate as that of the United States. From a total of about 721,000 metric tons in 1897 the production has increased to about 965,000 tons in 1907. If we consider all countries except the United States, the figures for the same period of eleven years would be 541,000 tons and 648,000 tons, an average annual increase of 9,700 metric tons. Upon closer examination it is found that from 1897 to 1903 the total production of all countries, excluding the United States, increased rapidly—in fact, at the remarkable rate of 23,000 tons per annum. On the other hand, a steady decrease has taken place since that time, from 702,000 metric tons in 1903 to 647,000 metric tons in 1907, equivalent to a rate of 11,000 tons per annum. And this has happened in the face of advancing lead prices.

Considering the foreign supply in more detail, the greatest output comes from Spain (186,000 tons in 1907). The quantity has remained approximately constant from 1897 up to the present time. Spain's resources of lead are known to be great, but it may be seriously doubted whether the present production can be materially increased. Germany contributed about 143,000 tons. Up to three or four years ago a steady increase had been shown in Germany, but in the last

[a] Prepared with the assistance of Mr. C. E. Siebenthal, of the U. S. Geological Survey.



PRODUCTION OF LEAD IN THE UNITED STATES FROM 1880 TO 1907.

few years, in spite of rising quotations, the production has receded. Australia yielded 97,000 metric tons, mainly from Broken Hill, but its output has been decreasing rapidly during the last few years from the maximum of 141,000 metric tons reached in 1903. Practically the same may be said of Mexico. From Mexican ores about 72,000 metric tons of lead were obtained in 1907. The rich ore deposits of Sierra Mojada and other places are being exhausted.

The facts given above are significant. They show that the lead deposits of the world are being heavily drawn upon and that, barring new discoveries of great importance, which are somewhat unlikely, a further reduction in the world's output is likely. This reduction will probably be accompanied by a rise in the price of the metal. An advance of a few cents per pound will no doubt create new and large ore reserves in many countries.

RESOURCES OF THE UNITED STATES.

Of the 365,000 tons of lead produced in the United States in 1907, Idaho and Missouri yielded 236,000 tons, or nearly two-thirds. The output of 1907 was divided approximately as follows:

	Short tons.
Southwestern Missouri	24,600
Southeastern Missouri	98,400
Idaho	113,000
Utah	62,000
Colorado	51,000
Other States	16,000
Total	365,000

In the following pages the production and possibilities of each State are taken up in sequence.

MISSOURI.

In southwestern Missouri lead is now mainly obtained as a by-product from crude zinc ores which average about one-half of 1 per cent in lead. The heavy lead ores occurred near the surface and are now almost exhausted. The present production of lead is mostly derived from the extensive flat ore bodies in the lower Carboniferous, known as the sheet ground. The portion of the sheet ground which has been mined up to date, say, in the last ten or twelve years, while comprising probably the richest part, constitutes not over the one-hundredth part of the probable sheet-ground territory. Much of this territory is, however, not workable at present ore prices. Large and economical plants will be one of the necessities of the future. Decreased cost of production and higher ore prices may lead to the opening of still deeper disseminated deposits which the drill has shown to exist at Joplin, Webb City, and Granby, and which have also been opened 10 miles south of Joplin. It is believed that the deposits of southwestern Missouri will be sufficient to keep up the present production for fifty years at least.

The production of southwestern Missouri remained fairly constant at 27,000 to 35,000 tons of lead concentrates per annum from 1894 to 1905. In 1906 and 1907 an advance took place, and in 1907 about 39,000 tons of concentrates were obtained.

In southeastern Missouri a pure lead ore is mined, containing an average of about 5 per cent of metallic lead. The important ore bodies occur disseminated within a Paleozoic limestone at depths of 100 to 600 feet in fairly well defined runs or ore bodies, some of which are over 5,000 feet in length. The production has been maintained for many years. In 1892 about 42,000 tons of concentrates and shipping ore were obtained. In 1901 this had increased to 110,000 tons. During the last few years the output has increased rapidly, and in 1907, 157,000 tons of concentrates were produced. This rapid advance is chiefly due to the enlarged plants of the St. Joseph Lead Company and affiliated interests, capable of handling 3,900 tons of ore per day, and to the 2,400-ton concentrating mill recently erected by the Federal Lead Company, which is allied to the American Smelting and Refining Company. No data are available giving the results of the extensive prospecting operations by diamond drills undertaken by these companies, nor has the region been covered by the investigations of the United States Geological Survey. Statements obtained from well-informed engineers indicate that the ore-bearing area covers from 30 to 40 square miles. While this ore-bearing area is large, it is by no means inexhaustible. It is believed that the maximum of production will be reached in a few years. The supply will, however, undoubtedly last for a great number of years, and it is undoubtedly true that there is a great extent of unprospected territory with possibilities of ore deposits at a considerable depth, especially on the south and southwest sides of the St. Francis Mountains.

IDAHO.

In Idaho the Cœur d'Alene district is the principal source of production. Discovered about 1885, this district has rapidly and continuously increased its production until it now exceeds 100,000 tons of metallic lead per annum. The deposits are strong fissure veins in quartzite. The principal properties are controlled by the Bunker Hill and Sullivan Mining and Concentrating Company and the Federal Mining and Smelting Company, the latter affiliated with the

American Smelting and Refining Company. The district has been studied by Mr. F. L. Ransome, of the Geological Survey,[a] who expresses his belief that the district gives promise of long-continued activity. Mr. Ransome also states that the ore shoots extend to great depth with remarkably little change in the character of the ore. The Bunker Hill and Sullivan mine, which has distributed over $9,000,000 in dividends, may reasonably be expected to continue its present rate of production for a score or more of years. Similar conclusions apply to several other mines. New discoveries will probably be made, as, indeed, in the last few years two important mines have been added to the producers. The total production of lead and silver will probably continue to increase for several years. The Bunker Hill and Sullivan, the greatest single producer, yielded in 1907 about 35,000 short tons of lead. On its lowest level the ore shoot is said to be as rich as in any of the upper workings, and there seems to be no reason why mining operations could not be extended for several thousand feet below this level. The underground workings have now, according to a recent circular to stockholders, undercut and partially developed 3,000,000 tons of ore, expected to contain 11 per cent of lead and 4.82 ounces of silver per ton, a total of about 330,000 tons of lead. A few of the deeper mines are now, according to Mr. Ransome, extracting ore much leaner than this and may cease to be profitable in a few years. There is also the probability that in general more zinc and less lead will be found as the mines attain greater depth. But on the whole the prospects decidedly encourage the belief that the Cœur d'Alene district will be able to maintain or somewhat increase its present production for some twenty-five years at least.

UTAH.

Utah has long been an important producer of lead, chiefly from three districts, the Park City, Bingham, and Tintic. The Frisco district has lost its one-time prestige in respect to this metal. The total output of Utah now (1907) stands at 64,000 tons, and for a number of years has remained fairly constant. The Park City district is the most productive, yielding about 23,000 tons per annum. The lead ore is contained in strong fissure veins and replacement bodies which promise a long-continued output. The bulk of the remainder, or about 40,000 tons, has until recently been derived from the Bingham and Tintic districts, but in late years the American Fork and Stockton districts have greatly increased their production. Utah is rich in lead ores, and its output bids fair to be continued on the present scale for many years to come. On the other hand, there is little probability of a greatly increased output. Nobody is in

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[a] Prof. Paper No. 62, U. S. Geological Survey.

position to furnish even approximate figures as to the reserves; it may be said, however, that few of the lead mines have reserves for more than two or three years ahead.

COLORADO.

Since 1879 Colorado has always been one of the most important lead-producing States. The production reached a maximum when the great ore bodies of Leadville were discovered about twenty-five years ago. It has fluctuated considerably, ranging from 40,000 tons to 80,000 tons of metallic lead between the years 1881 and 1908. During the last few years it has slowly declined and in 1907 was estimated to be 51,000 tons. Leadville has always been the most prominent district and its production was greatest when the enormous bodies of carbonate ore were worked, from 1880 to 1890. During recent years the output of Leadville has remained fairly constant at about 23,000 tons, or one-half of the total production of Colorado. The rich oxidized ores are almost exhausted. The deeper ore bodies are of great size but are poor in lead. It is largely owing to the utilization of zinc ores that Leadville has been able to maintain its production; the tonnage of zinc-lead ores, poor in lead, is now about one-third of the tonnage of the lead ores and the siliceous ores. Undoubtedly a large output of lead can be maintained for many years, but it will probably slowly decrease. The rest of the Colorado lead is mainly derived from Aspen and Creede. The former district is slowly decreasing in importance. Regarding the latter, the information at hand is not extensive, but it is believed that the district is in position to maintain its output for a number of years.

From the preceding it appears that there is little chance of increase in the lead production of Colorado. More probably it will gradually decrease. The State is rather throughly prospected, and the chance of new discoveries is correspondingly small.

OTHER STATES.

None of the other States yield enough to become a seriously considered factor. The total output from them was 16,000 tons in 1907. Probably many districts will increase in importance; others will fall out. For a number of years to come we may count with some confidence on this amount as their aggregate total. The Eureka mines in Nevada, once prominent, are now being rèopened, but thus far no ore bodies similar in importance to the old bonanzas have been reported. The railroads now being built in the State will open a considerable territory, which will yield a fairly large amount of lead from newly developed smaller districts or from rehabilitated old districts like Pioche. Discoveries of new lead-producing districts like Leadville or Park City or the Cœur d'Alene are of course always possible, but they do not seem very likely.

Summing up these data, it is believed that the lead production of the United States can be maintained at the present figures for a number of years—possibly twenty years—but that after some such time it would be more likely to decrease. Barring new discoveries of great value, a continued increase of production, like that which has taken place in the United States since 1895, is very improbable. With increasing demands for consumption the price of lead would gradually rise, and in such case of course each cent permanently added to the price of the metal would make available large additional ore reserves, but even at an increased price there is little probability of an indefinite increase on the scale of the last few years.

CONSUMPTION.

For the last ten years the United States has consumed all of the domestic lead produced, and in addition a variable but small amount has been imported. The consumption has practically kept step with the production.

A feature of much interest is that over one-third of the lead is used in the manufacture of white lead and consumed as paint. This feature is shown in the diagram. (See Pl. X.) In 1907, 135,000 tons of metallic lead were so used. White lead is used more than any other substance for paint, although the manufacture of zinc white and zinc-lead white has taken great steps forward during the last few years. Of course the lead so used is absolutely lost, and it does seem as if for these purposes some other material might be substituted for so valuable a metal, especially when, as shown above, the ore reserves are relatively low. Probably no other nation uses lead paint to the same extent as the United States; partly because here wood construction prevails; partly because our greater prosperity allows the use of more expensive paint. With general substitution of brick, stone, or cement (of which our resources are inexhaustible) for wood (of which our supply is rapidly diminishing), the demand for lead white would greatly decrease. Anything that could be done to encourage this change would be desirable.

With increasing production and price a greater quantity of scrap will each year be remelted for consumption. In 1907, according to returns made to the United States Geological Survey, at least 25,000 tons of lead were thus returned to consumption; the latter is thus in reality at least 25,000 tons greater than the figures of production would indicate.

WASTE.

There is little waste in the mining of lead ores. Neither is there much waste in the smelting of the ores; besides, the slags are of course always available for retreatment, if necessary. The loss in smelting and refining is usually estimated as 5 per cent, although this figure is probably somewhat too high.

The greatest waste takes place in the concentration of lead ores. It is not nearly so great as in case of copper and zinc, but doubtless often amounts to 15 or 20 per cent. The best way to mitigate this feature would be to compel all owners of concentrating works to store their tailings.

The improvements in both concentration and smelting have been very great in the last fifteen years, and this fact has, of course, enabled the miners to handle lower grades of ore. A lead ore containing 4½ per cent of metallic lead is now worked in southeastern Missouri, and ore containing 5½ to 6½ per cent (with 2 to 3 ounces of silver) in the Cœur d'Alene district. Further reduction in costs is probable, but is not likely to be great as long as the present high scale of wages in the West continues.

TARIFF ON LEAD AND LEAD ORES.

The lead-mining industry has been to a high degree artificially stimulated by the duty on refined lead and lead ores. Under this protection our own resources have been strained to the utmost. We have put a premium on the output of lead and the result is shown in the price of the metal, which is higher in New York than in foreign markets.

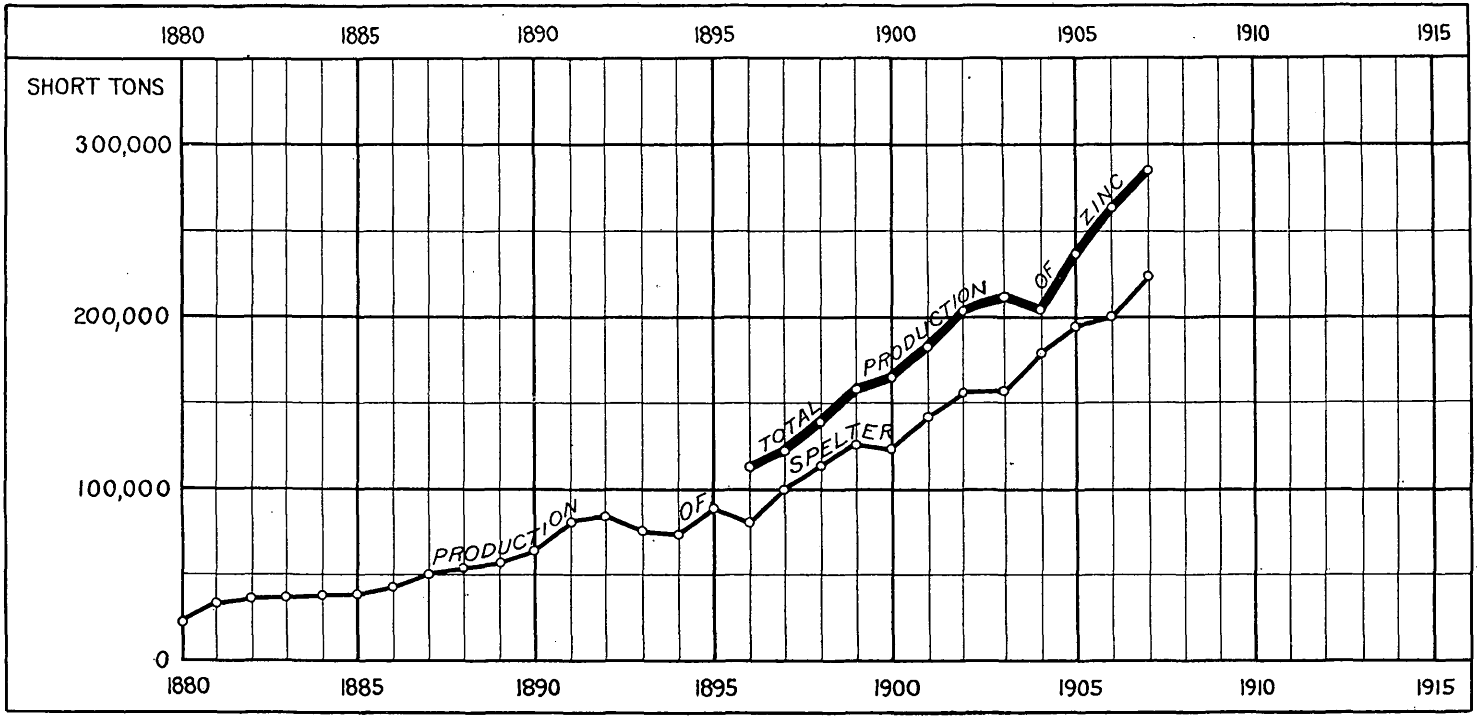
ZINC.[a]

PRODUCTION OF THE UNITED STATES.

The zinc-smelting industry in the United States is of comparatively recent origin. From a small beginning of 23,000 tons of spelter in 1880, the production increased at a moderately rapid rate up to 1896, as shown by the diagram (Pl. XI). This total increase in seventeen years was only about 60,000 tons, or at a rate of 3,500 tons per annum. From 1896 a much more rapid rate began. The average increase from 1896 to 1907 was at the rate of 14,000 tons per annum, or from 81,000 tons in 1896 to 223,000 tons in 1907. The rate of increase has been fairly uniform within this period, but was distinctly greater from 1903 to 1907 than from 1896 to 1903, the average annual increase during the more recent period amounting to 18,000 tons.

All these figures, it should be remembered, refer to spelter; a large part of the zinc ore is, however, used for pigments, chiefly zinc oxide, partly also zinc-lead white. The upper curve in the diagram shows

[a] Prepared with the assistance of Mr. C. E. Siebenthal, of the U. S. Geological Survey.



PRODUCTION OF ZINC IN THE UNITED STATES FROM 1880 TO 1907.

Upper line shows total production of zinc as spelter and as zinc in zinc white, manufactured from ore. Lower line shows production of spelter.

the zinc in pigments added to the production of spelter. The amount of zinc used annually for paints has doubled since 1896 and is now about 60,000 tons. Taking this into consideration it is seen that the total production of zinc in the United States was 280,700 tons in 1907, and that the annual increase since 1904 has been 32,000 tons in 1905, 27,000 tons in 1906, and 21,000 tons in 1907. Assuming that a straight line from 1896 to 1907 represents the average tendency, the production in 1910 would be about 325,000 tons; in 1915, 395,000; and in 1920, 475,000 tons. Should the substitution of zinc oxide for white lead proceed on a still larger scale in the future than in the past, which seems possible, the figures at the years mentioned would be very materially increased.

PRODUCTION OF THE WORLD.

The world's production of zinc has increased since 1896 at a very rapid rate, but not quite at the pace set by the United States. The total production increased from 422,000 metric tons in 1896 to 737,000 metric tons in 1907. The production from all sources, excepting the United States, amounted to 352,000 metric tons in 1896 and 510,000 metric tons in 1907, an average annual increase of 14,300 tons.

The celebrated zinc mines in Belgium are still producing heavily, as are the mines of Silesia and at other points in Germany. New and very extensive supplies of ore are being received in Europe from Mexico and Australia, and deposits of great magnitude are reported to exist in Africa. The successful solution of the problem of ore concentration at Broken Hill, New South Wales, will enormously increase the shipments of Australian ores to European smelters, and it is considered possible that the mines of Germany and Belgium may have to reduce their output to avoid overproduction of zinc.

The United States now ranks first in production, having surpassed Germany in 1907.

RESOURCES OF THE UNITED STATES.

The production of zinc (spelter and zinc in oxide) in 1907 is divided as follows among the States:

	Short tons.
Missouri	142,000
Wisconsin	17,000
Kansas	14,000
New Jersey	59,500
Colorado	33,600
Other States	14,600
Total	280,700

MISSOURI.

It will be seen that Missouri occupies the most commanding position, producing over one-half of the total domestic output. Practically all of this is derived from the southwestern or Joplin district. The ores now of most importance are contained in flat deposits in the so-called "sheet ground," which, at a depth of 150 to 250 feet, underlie a large area in this region. The known sheet ground is constantly increased; the extent of the actual known ore reserves is an unknown quantity; the extent of the area of possible ore is very large. It can be said with fair confidence that deposits of zinc ores underlie 50 square miles of territory, with strong probability that further exploration will add another 50 square miles. The portion of the sheet ground which has been worked during the last ten or twelve years, since such mining was first attempted, is between 1 and 2 square miles. Much of the remaining territory is certainly poor and contains considerably less than 3 per cent of zinc sulphide (including some lead), and whether it can be profitably worked is largely dependent upon royalty to the landowner as well as price of zinc. There is also some probability of opening lower deposits of zinc-bearing ground which have been shown to exist at Joplin, Webb City, and Granby and which now are being worked at Aurora at a depth of 325 feet. Superficial deposits will doubtless continue to be discovered and worked, though probably in lessening number and extent in the future. As the result of special study of the Joplin district by the United States Geological Survey, it is thought that the probable ore reserves will be sufficient to keep up the present production for fifty years at least.

KANSAS AND OKLAHOMA.

The zinc-bearing cherts and limestones extend from Joplin into the adjoining States of Kansas and Oklahoma. In Kansas the future can not be predicted, as the deposits so far developed have not been of sheet formation, but there are possibilities of finding extensive deposits in virgin territory and at greater depth in known localities. In Oklahoma the production is now small, but there is in the Quapaw district at least 12 square miles of ore-bearing blanket breccia. Very promising deposits have been opened at Miami, and the blanket breccia probably extends in this direction, making it reasonably certain that the mineralized area is as much as 20 square miles in extent, most of which will be available mining territory when ore yielding 2 per cent of concentrates can be profitably worked.

WISCONSIN.

According to Mr. H. Foster Bain, the extent of the zinc deposits in Wisconsin is fairly well known. The ore does not, as in Missouri, form extensive flat sheets, but shorter "pitches" and "flats." The zinc ore is usually found below the already mined lead deposits, and drilling operations during the last few years have given encouraging results. The production has increased rapidly and with higher zinc prices will probably increase still further. No estimate of actual or probable ore reserves can be given, but there is little doubt that the present production, with zinc at 5 or 6 cents per pound, can be continued for many years.

NEW JERSEY.

The large and in many respects remarkable deposit at Franklin Furnace is the only occurrence of importance in New Jersey. No recent estimate of the quantity of ore is available, but, according to a report by Nason,[a] the ore body in 1894 contained about 8,000,000 tons. According to the reports of the New Jersey Geological Survey, approximately 2,500,000 tons have been mined since 1904. The figures for the total ore reserves may be rather far off the mark, but they serve to show that the ore body is known to have definite limits and that its exhaustion is probably a matter of fifteen to twenty-five years at the present rate of ore production.

COLORADO.

About 1901 Colorado began to ship zinc ores to the smelters and shortly afterward a zinc smelter was built at Pueblo. The production rose rapidly, and, according to the mine reports of the United States Geological Survey, in 1906 attained 43,000 tons, calculated as probably recovered spelter and zinc in paint. In 1907, when the conditions, at least during the latter part of the year, were less favorable, the production was 30,400 tons. The larger part of this came from Leadville, in which camp the lower levels had disclosed large quantities of ore consisting of pyrite, zinc blende, and a little galena. Recent improvement in concentrating processes had made possible the recovery of this zinc and its separation from the pyrite. Large quantities of zinc also came from the Tenmile, Red Cliff, Aspen, Creede, Breckenridge, and Clear Creek districts. The margin of profit was in many cases small, no payment was as a rule obtained for the silver and lead contained in the ores, and the losses in concen-

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[a] Trans. Am. Inst. Min. Eng., 1894.

tration were great. When the lower prices of 1907 were established the majority of the mines ceased shipments.

No figures of ore reserves even approximately correct are available to the Geological Survey, nor can they be obtained, but there is no question whatever that the resources of Colorado in zinc ores are very large, and that with favorable prices an output much larger than that of 1906 could easily be yielded by the State for a long period of years. The ores occur under entirely different conditions from those of the Central States. The deposits are fissure veins or irregular replacement ores in limestone, and are nearly always mixed, i. e., contain silver, copper, lead, and more rarely gold. Many mines once worked for lead have been impoverished by the prevalence of zinc in lower levels.

OTHER STATES.

Conditions similar to those in Colorado prevail in many of the Western States, notably in Utah and Idaho, both of which shipped a considerable amount of zinc ores in 1906 and 1907. From Park City and Frisco in Utah and from the Cœur d'Alene district in Idaho important shipments were made. New Mexico, though not figuring conspicuously in the production of 1907, has some very large zinc deposits at Magdalena and smaller deposits at many places. Its yield of zinc in 1906 was about 8,000 tons, and with favorable conditions this amount could probably be doubled and be continued for a considerable period of years.

Zinc ores in considerable quantities could be furnished by Arizona and Nevada. Prospecting for these ores has not been especially active in the West. In fact, deposits containing zinc have until within a few years rather been shunned on account of the difficulty of treating such ores in copper and lead furnaces and the difficulty of marketing them as zinc ores with profit. New discoveries may therefore be anticipated.

In conclusion, the supply of zinc at prices of 4 to 5 cents is not very large, and will come chiefly from Missouri and New Jersey. At prices above 5 cents the supply will probably be ample for such length of time as we can reasonably foresee. It is thought that our resources of zinc, especially in the West, have just begun to be developed.

CONSUMPTION.

Since 1876 the domestic production has been sufficient to supply the demand, and the importations have been small. A small amount of high-grade spelter and ore has been exported, mostly from New Jersey. There is, it is true, an import duty on spelter practically prohibiting foreign importations, but on the other hand, during the last three years 25,000 tons of spelter have been obtained per annum from Mexican ores, which is equivalent to about one-eighth or one-ninth of our domestic production. There has been a long controversy about the construction of the law in respect to zinc ores. The case is still in the courts and, pending final decision, duties are still collected, to be refunded later should zinc ores be adjudged duty free.

As already noted, about 60,000 tons of the metal are used per annum for the manufacture of white paint. This amounts to one-sixth of the whole output, and is of course permanently lost. Next in importance comes the metal used for galvanizing, and this consumed, in 1905, 100,000 tons; in 1906, 124,000 tons; and in 1907, 149,000 tons, an increase of 49 per cent in two years. In 1907 this amounted to more than half of the total production of zinc. The remainder of the spelter output is about equally distributed between brass and sheet zinc. All these products seem indispensable for the growth and development of the industries, and it is believed that the consumption of zinc will continue to increase at the recent rate for several years to come.

The zinc industry has been less protected than lead mining and smelting, and it appears to be in a healthy condition. There is no single concern controlling the output or the principal part of the output.

Much zinc can be recovered from the galvanized products, and this recovered metal, which in 1907 amounted to 19,000 tons or more, will of course increase as the output grows larger.

WASTE.

In no metal industry is the waste more startling than it is in the production of zinc. In mining, Missouri must be considered first. Owing to the occurrence of the ore in flat sheets, it is necessary to leave pillars to support the roof, filling or timbering being too expensive. About 14 per cent of the ore therefore remains in the mine, although, of course, care is usually taken to select the poorer ground for pillars as far as possible. In the West, owing to the expensive treatment and shipment of the ore, much low-grade ore is left in the mine, but this is not necessarily a complete loss unless the mine is entirely wrecked.

In concentrating, the losses are enormous. Somewhat better conditions now prevail, but in many cases at least not more than 60 per cent of the assay value is saved in the concentrating works. From 30 to 35 per cent is perhaps an average loss. Southwestern Missouri has been the chief offender in this respect. While the mining and milling costs there have been extremely low, this has been accomplished at a heavy loss of metal. The miner has not been entirely to blame, for the heavy royalties exacted by the landowners have forced him to adopt these wasteful methods. Lower royalties, better concentration works, and obligatory storage of tailings will help these conditions.

In the smelting of zinc ores the loss is heavier than in any other metal; the average is probably nearly 15 per cent of the assay value, and the loss is heavier in western complex ores, containing much iron, than in Missouri Valley ores. It is claimed that the smelter practice has been behind that of Europe. These conditions are being remedied, but still further metallurgical improvements are most urgently desirable and will be soon attained. The western ores usually contain silver and lead; sometimes also copper. Under present conditions these metals are often wasted, and only under exceptional conditions does the miner obtain payment for them. There is vast room for improvements in the zinc industry, and attention to the matter will materially increase the life of our zinc deposits.

The total loss from ore in the ground to spelter is rarely less than 40 per cent.

THE PHOSPHATE DEPOSITS OF THE UNITED STATES.

By F. B. Van Horn.

INTRODUCTION.

The occurrence of rock phosphates in the United States has a very important bearing upon the agricultural industry, since many plants can not exist without the presence of phosphoric acid in the soil. Growing crops deplete the soil of its phosphoric acid, and if no steps are taken to restore this substance the soil must eventually become nonproducing.

Florida, South Carolina, and Tennessee have for several years been the main sources of phosphate in the United States. North Carolina, Alabama, and Pennsylvania have produced phosphate rock, but never on a large scale, and there is at present no production from these States. In 1900 Arkansas entered the field as a producer, and in 1906 a new field was discovered in Wyoming, Idaho, and Utah.

DEVELOPMENT OF THE INDUSTRY.

Phosphate mining began in the United States in 1867 in South Carolina. The existence of the rock had been known since 1837, but the possibilities of its commercial use were not recognized until 1859. According to Otto A. Moses:[a]

In 1859 Professor Shepard and Col. L. M. Hatch suggested the utilization of phosphatic marls in the manufacture of commercial fertilizers and started a factory at or near Charleston, which was, however, soon abandoned. Remains of their compost heap were utilized by neighboring farmers with good effect long after the war.

At the close of the war Dr. N. A. Pratt, formerly connected with the niter bureau of the Confederacy, visited Charleston with the object of starting sulphuric acid chambers. About this time Dr. St. Julien Ravenel, of Charleston, who had mined marl extensively at Stoneys Landing, on Cooper River, for the manufacture of cements, noticed the nodules, analyzed some of them, and found them to contain much phosphate of lime. He became engaged soon after in the manufacture of commercial fertilizers from foreign phosphate rocks. Then followed the discovery (in August, 1867) which has been of such vital importance to agriculture and the prosperity of South Carolina. Pratt and Holmes

[a] Mineral Resources U. S. for 1882, U. S. Geol. Survey, 1883, p. 512.

(Charleston Mining Company), Ravenel and Dukes (Wando Company), then located territory. The value of the deposits became known; other available beds were discovered, and many persons and considerable capital were soon employed in developing the new industry by mining the crude rock and exporting or manufacturing it on the spot into superphosphates. Later on the beds of many navigable streams were found to be largely paved with the valuable substance.

Until 1888 South Carolina enjoyed a monopoly of the phosphate industry of the United States. In that year Florida came forward as a phosphate State, with a production of 3,000 long tons. In 1904 the production surpassed that of South Carolina, and Florida has maintained its lead up to the present time.

In 1892 phosphate was discovered in Tennessee, and two years later the production from that State was 19,188 long tons. In 1899 Tennessee went ahead of South Carolina, the production from the latter State having decreased steadily since 1894.

PRODUCTION.

The production of phosphate from South Carolina from the beginning of the industry in 1867 to the year 1888, during which period that State was the only producer, was 4,442,945 long tons, valued at $23,697,019. The following table shows the total production from the United States from 1867 to 1907:

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Long tons.			*Long tons.*	
1867–1887	4,442,945	$23,697,019	1899	1,515,702	$5,084,076
1888	448,567	2,018,552	1900	1,491,216	5,084,248
1889	550,245	2,937,776	1901	1,483,723	5,316,403
1890	510,499	3,213,795	1902	1,490,314	4,693,444
1891	587,988	3,651,150	1903	1,581,576	5,319,294
1892	681,571	3,296,227	1904	1,874,428	6,580,875
1893	941,368	4,136,070	1905	1,947,190	6,763,403
1894	996,949	3,479,547	1906	2,080,957	8,579,437
1895	1,038,551	3,606,094	1907	2,265,343	10,653,558
1896	930,779	2,803,372			
1897	1,039,345	2,673,202	Total	29,208,141	117,316,002
1898	1,308,885	3,453,460			

Of this amount South Carolina has furnished 11,912,959 tons; Florida, 12,395,731 tons; Tennessee, 4,859,991 tons; and other States, 39,460 tons. In twenty years Florida has produced more phosphate than has South Carolina in thirty-one years.

GEOLOGIC OCCURRENCE.

The phosphate deposits range in age from the Ordovician in Tennessee to the Tertiary in Florida, occurring also in the Devonian in Tennessee and Arkansas, and in the Carboniferous in the Wyoming-Idaho-Utah field.

FLORIDA DEPOSITS.

DISTRIBUTION.

Phosphates occur in a general way along the west coast of Florida, principally in Polk, De Soto, Hillsboro, Pasco, Hernando, Sumter, Citrus, Marion, and Levy counties, although the rock has been found also in Alachua, Suwanee, Lafayette, Taylor, Jefferson, Wakulla, and Liberty counties. There are three classes of deposits in Florida—hard rock, land pebble, and river pebble. These deposits vary in percentage of tricalcium phosphate from 78 per cent to 80 per cent in the hard rock, through 68 per cent to 70 per cent in the land pebble, to about 65 per cent in the river pebble.

Hard rock.—The hard-rock phosphate belongs to the Eocene and the Miocene periods. In the former it consists entirely of a bowlder deposit in a soft matrix of phosphatic sands, clays, and other materials, while in the latter it is also found at many places as a bedded deposit in situ. The bowlders vary in size from 2 or 3 inches to 8 or 10 feet, and lie embedded in all positions, surrounded by sand and clay containing more or less phosphate of lime in finer particles, resulting from a general distribution of the disintegrated portions of the bowlders during deposition. The deposits themselves vary from small pockets to those several acres in extent. The phosphate content of this class of deposits is from 10 per cent to 30 per cent of the mass.

Land pebble.—The pebbles making up this deposit range from minute size to that of a walnut. They are originally white in color, but become dark colored when subjected to water action. They are embedded in sand and are underlain by a stratum of tough, stiff, clayey material known as "bed rock." Above the deposit is an overburden from 1 to 25 feet thick consisting of sand and limestone bowlders. The proportion of phosphate to other rock of this class of deposits varies from 1 to 10 to 1 to 4, or from 10 per cent to 25 per cent.

River pebble.—This class of deposit is very similar to the land pebble and derives its name from its manner of occurrence in the river beds. The pebbles are white to dark brown in color and of about the same size as the land pebbles. They occur in the form of bars in the rivers, and are derived from the formations through which the river flows.

DEVELOPMENT AND PRODUCTION.

The year 1887 marked the beginning of the phosphate industry in Florida. In 1888 the first shipment of pebble phosphate from Peace River was made to Atlanta, Ga. In 1889 the hard-rock phosphate was discovered in Marion County, and in 1890 the land-pebble area was opened up in Polk County. The growth of the industry has been rapid and remarkable, until now Florida is the largest producer of phosphate rock in the United States.

The first production consisted of 3,000 tons in 1888, and twenty years later the output for the year was 1,357,365 tons, or nearly 60 per cent of the entire production of the United States in 1907. Following is a table showing the marketed production and value of phosphate rock from Florida, by years, since the first shipment:

Output of phosphate rock in Florida, based on marketed product, 1888–1907.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Long tons.			*Long tons.*	
1888	3,000	$21,000	1899	726,420	$2,804,061
1889	4,100	28,000	1900	706,243	2,983,312
1890	46,501	338,190	1901	751,996	3,159,473
1891	112,482	703,013	1902	785,430	2,564,197
1892	287,343	1,418,418	1903	860,336	2,986,824
1893	438,804	1,979,056	1904	1,072,951	3,974,304
1894	527,653	1,666,813	1905	1,194,106	4,251,845
1895	568,061	2,112,902	1906	1,304,505	5,585,578
1896	495,199	1,547,353	1907	1,357,365	6,577,757
1897	552,342	1,493,515			
1898	600,894	1,847,796	Total	12,395,731	48,043,407

SOUTH CAROLINA DEPOSITS.

DISTRIBUTION.

The South Carolina phosphate beds occur interruptedly along a belt the lower limit of which extends along a meandering line from a point near the source of the Wando River in Charleston County to the mouth of the Broad River. The belt follows the coast, running back as far as 20 miles from the ocean.

In South Carolina the phosphate rock occurs in two forms: The land rock and the river rock, running about 58 and 55 per cent in tricalcium phosphate.

Land rock.—The land rock is very probably of Miocene age, and consists of so-called pebble rock which is in fact a solid mass from which the calcium carbonate has been leached out and partially replaced by phosphate, leaving cavities which connect and penetrate through the rock, giving it the appearance of being made up of separate pebbles. The rock runs from 1 to 3 feet in thickness, and is overlain by a greensand marl.

River rock.—The river rock is so called because it is mined from the river channels. It consists essentially of the water-rounded fragments of the land rock.

DEVELOPMENT AND PRODUCTION.

As already stated, phosphate rock was discovered in South Carolina in 1867, during which year 6 tons were marketed. From this time on the production increased until 1889, when it amounted to

541,645 long tons. Since 1893 the production has almost steadily decreased, and in 1899 Florida took the lead in the industry. In 1907 only 257,221 tons were marketed from South Carolina. The total production and value of phosphate rock from South Carolina, by years, from 1867 to 1907, is shown in the following table:

Production of marketed phosphate rock in South Carolina, 1867–1907.

Year ending—	Quantity.	Value.	Year ending—	Quantity.	Value.
May 31—	*Long tons.*		December 31—Continued.	*Long tons.*	
1867	6		1888	448,567	$2,018,552
1868	12,262		1889	541,645	2,892,276
1869	31,958		1890	463,998	2,875,605
1870	65,241		1891	475,506	2,948,138
1871	74,188		1892	394,228	1,877,709
1872	58,760		1893	502,564	2,157,014
1873	79,203		1894	450,108	1,745,576
1874	109,340	$7,248,380	1895	431,975	1,411,032
1875	122,790		1896	402,423	1,181,649
1876	132,478		1897	358,280	986,572
1877	163,000		1898	399,884	1,107,272
1878	210,322		1899	356,650	1,078,099
1879	199,365		1900	329,173	1,041,970
1880	190,763		1901	321,181	961,840
1881	266,734	1,980,259	1902	313,365	919,725
1882	332,077	1,992,462	1903	258,540	783,803
1883	378,380	2,270,280	1904	270,806	861,317
1884	431,779	2,374,784	1905	270,225	878,169
1885	395,403	2,339,468	1906	223,675	817,068
December 31—			1907	257,221	980,867
1885	277,789	1,805,629			
1886	430,549	1,848,939	Total	11,912,959	53,221,272
1887	480,558	1,836,818			

TENNESSEE DEPOSITS.

DISTRIBUTION.

The deposits of phosphate in Tennessee lie mainly in Maury, Hickman, Perry, and Lewis counties, with some deposits in Giles, Williamson, Davidson, Sumner, and Decatur counties.

There are three commercially important classes of phosphate rock in Tennessee: The brown residual phosphate, the blue or black bedded phosphate, and the white phosphate. These range in phosphatic content from 70 per cent to 80 per cent lime phosphate in the brown rock to 75 to 85 per cent lime phosphate in the white rock, although in all three classes are to be found portions which run as high as 90 per cent.

BROWN RESIDUAL PHOSPHATE.

This variety of phosphate occurs mainly in Maury County. It is of Ordovician age, and is the result of the leaching process to which the phosphatic limestones have been subjected. Surface waters bearing carbonic and other organic acids have dissolved and carried away a large part of the calcium carbonate forming the limestone, leaving the calcium phosphate as a residual deposit. The brown phosphate is from 2 to 6 or 8 feet in thickness at various points.

BLUE OR BLACK BEDDED PHOSPHATE.

These deposits are of Devonian age, and show variations from oolitic through compact and conglomeratic to shaly forms. There is also a nodular variety which occurs in a greensand formation immediately overlying the black shale. The bedded deposit occurs in seams varying from 1 to 50 inches in thickness, but where carrying high-grade rock the bed is seldom more than 20 inches thick. The phosphatic content ranges from 30 to 85 per cent. The nodular variety, which is embedded in a greensand matrix, runs about 60 per cent lime phosphate, but it is not practicable to work it except at points where the bedded rock is mined by stripping off the overburden.

WHITE PHOSPHATE.

This rock is of post-Tertiary age, and occurs in three different forms, stony, brecciated, and lamellar. The stony phase contains usually only about 50 per cent of lime phosphate and is not worked at the present time. The lamellar forms were deposited in caves, and are thus of irregular shape and extent. The breccia consists of fragments of Carboniferous chert cemented by lime phosphate. The chert fragments vary from a fraction of an inch to 3 or 4 inches in diameter. The lamellar variety consists of thin parallel layers or plates about 1 inch thick, but several inches long and broad.

The white phosphate has thus far been found only in Perry and Decatur counties. It runs sometimes as high as 85 per cent phosphate of lime.

DEVELOPMENT AND PRODUCTION.

The blue bedded phosphate of Tennessee was discovered in 1893 and was mined until 1896, when the brown rock was found to be valuable. The favorable location of this brown rock led to the cessation of blue-rock mining for the time. The white rock has not as yet been extensively mined.

The total production of phosphate rock from Tennessee from the first operations in 1894 to the end of 1907 is as follows:

Production of marketed phosphate rock in Tennessee, 1894–1907.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Long tons.			*Long tons.*	
1894	19,188	$67,158	1902	390,799	$1,206,647
1895	38,515	82,160	1903	460,530	1,543,567
1896	26,157	57,370	1904	530,571	1,745,054
1897	128,723	193,115	1905	482,859	1,633,389
1898	308,107	498,392	1906	547,677	2,147,991
1899	424,109	1,177,160	1907	638,612	3,047,836
1900	454,491	1,328,707			
1901	409,653	1,192,090	Total	4,859,991	15,920,636

ARKANSAS DEPOSITS.

The developed phosphate deposits of Arkansas are on Lafferty Creek, on the western edge of Independence County. The rock itself is light gray, homogeneous, and conglomeratic, with small pebbles more or less angular in form. The phosphate bed runs from 2 to 6 feet in thickness, and varies from 25 to 73 per cent phosphate of lime.

The Arkansas phosphates as such were discovered in 1895, but it was not until 1900 that any attempt was made to develop them. At that time the Arkansas Phosphate Company was formed, and a mining and milling plant was erected. After only a few months' operation this plant was destroyed by fire, and it has only been within the last two years that any production has been marketed, and that has been a small one. Analyses show that very little of this rock is high grade, and the field will probably not be operated until 30 to 50 per cent rock can be utilized.

WYOMING-IDAHO-UTAH DEPOSITS.

DISTRIBUTION.

Within the last few years a large area of phosphate-bearing rock has been discovered in the western United States. This discovery is of much importance since it opens a new field in an area which is tributary to the great agricultural region of the Middle West. The phosphate occurs over a considerable area in southeastern Idaho, southwestern Wyoming, and northeastern Utah. It is found in rocks of upper Carboniferous age in a series of shales and limestones, 100 feet thick, within which are several beds of phosphate rock ranging in thickness from a few inches to 10 feet. At the base of the series is a limestone, and 6 to 8 inches of soft brown shale separates this from the principal phosphate bed, which is 5 to 6 feet thick. This phosphate bed is oolitic in character and high in phosphoric acid. There are several other beds ranging from a few inches to 10 feet in thickness, separated by thin beds of limestone or shale, in the series. Usually one and sometimes two of these beds at a given section are workable, and probably some of the others will eventually be mined. The lime phosphate content in the workable beds varies from 65 to 80 per cent, with an average of 72 per cent.

DEVELOPMENT AND PRODUCTION.

The newness of the field, the lack of transportation facilities, and the high freight rates have prevented the development of this phosphate territory to a great extent, although there has been some shipment from Montpelier, Idaho, in the last two years. According to F. B. Weeks,[a] who recently prepared a report upon these phosphates:

This field embraces the largest area of known phosphate beds in the world, and at some future time it will doubtless furnish a large part of the world's production of commercial fertilizer. The development of intensive farming as a result of the reclamation of arid lands in the West will afford an increasing home market.

PHOSPHATE AS A FERTILIZER.

According to a letter from Dr. W. L. Rasin, of Baltimore:[b]

The manufacture of chemical fertilizers in the United States began about 1850. In that year Dr. P. S. Chappell and Mr. William Davison, of Baltimore, made some fertilizer in an experimental way. About the same time Professor Mapes was experimenting. Later De Burg utilized the spent bone black derived from the sugar refineries and made quite a quantity of "dissolved bone black" (superphosphate). In 1853 or 1854 Dr. P. S. Chappell commenced the manufacture of fertilizers, as did B. M. Rhodes, both of Baltimore. In 1855 Mr. John Kettlewell, recognizing the fact that Peruvian guano (then becoming quite popular and containing at that time 18 to 21 per cent ammonia) was too stimulating and deficient in plant food (phosphates), conceived the idea of manipulating the Mexican guano, containing no ammonia but 50 to 60 per cent of (bone) phosphate of lime, and called his preparation "Kettlewell's manipulated guano."

While in 1856 the sales of Peruvian guano had increased to 50,000 tons, and of Mexican guano to some 10,000 tons, there was not at that date 20,000 tons of artificial fertilizers manufactured in the entire country. Baltimore was not only the pioneer but the principal market for fertilizers until some time after the civil war.

Since the discovery of valuable deposits of phosphate rock in South Carolina in 1867, the fertilizer industry has grown rapidly, and in 1900 there were 478 factories in the United States, with an output of 2,887,004 tons of fertilizer, valued at $41,997,673.

AVAILABLE PHOSPHATE DEPOSITS.

The known phosphate deposits of the United States are distributed principally among four localities: (1) Along the west coast of Florida, going back 20 to 25 miles inland; (2) along the coast of South Carolina, extending 6 to 20 miles inland; (3) in central Tennessee; and (4) in an area comprising southeastern Idaho, southwestern Wyoming, and northeastern Utah. In addition to these areas

[a] Contributions to economic geology, 1907, pt. 1; Bull. U. S. Geol. Survey No. 340, 1908, pp. 441–447.

[b] Twelfth Census Report, Vol. X, Pt. IV, p. 562.

some deposits occur in north-central Arkansas, along the Georgia-Florida state line, and in North Carolina, Alabama, and Mississippi, but these are mainly of low grade and are not utilized at present. The first three of the important deposits have been worked for thirteen to thirty years, while the fourth is a new field which has as yet had but a small output.

Owing to very incomplete data any estimate as to available supply of phosphate rock must, at best, be unsatisfactory. Taking South Carolina as the field most likely to first reach the exhaustion point, Florida second, Tennessee third, and the practically untouched deposits of Idaho-Wyoming-Utah last, an estimate of the available supply and possible duration is given, based on the past production.

South Carolina.—By reference to the table of total production (p. 158) it will be seen that the output gradually increased from 1867 until 1889, when the largest production, 541,645 long tons, was marketed. Since 1893 the output has decreased at about the same rate as the increase previous to that year. In the twenty-seven years from 1867 to 1893 the production was 7,269,453 long tons, and in the fourteen years since 1893 the production has been only 4,643,506 tons, or 63.8 per cent of the production to 1893. Arguing from these figures, it is concluded that the amount of phosphate rock remaining to be mined in South Carolina is not more than 3,000,000 tons, but it is possible that by careful deeper prospecting these figures may be increased. At the present rate of production this field has a probable life of not more than fifteen years.

Florida.—The total production of phosphate rock in Florida since the beginning of the industry in 1888 has been 12,395,731 tons. As shown by the table on page 160 there has been a steady increase in production, but since 1904, when the increase in output over the previous year was 212,615 tons, the increase has been smaller each year, until in 1907 it was only 52,860 tons. When it is remembered that the phosphate deposits in Florida are not continuous beds, but rather pockets, and that practically all the phosphate-bearing areas in the State have already been discovered, it appears conservative to estimate an available supply remaining at not more than 15,000,000 tons, or a little more than has already been produced. At the present rate of production the phosphates of Florida would have a life of approximately twelve years.

Tennessee.—The total production of phosphate rock in Tennessee since the discovery in 1893 has been 4,859,991 tons. In 1907 the production was the largest in the State's history, amounting to 638,612 tons. In Tennessee the phosphates exist as brown rock, blue bedded rock, and white rock. The brown rock is the result of leaching processes in an original phosphatic limestone and occurs usually on the surface. The ease of mining and accessibility to transportation have contributed to the rapid working out of this class of rock, but there still remains enough of it to last possibly five years at the present rate of production; that is, about 3,000,000 tons. The blue bedded rock has not been worked considerably in the past, but with the approaching exhaustion of the brown rock a good deal of activity is now being shown. The bedded character of this rock and its continuity over large areas make it certain that large amounts are still available. According to the American Fertilizer for November, a company has been organized and has taken up 16,375 acres of phosphate land, with 10,000 acres under option. An estimate of 1,500 tons to the acre gives approximately 40,000,000 tons, but this estimate is very conservative. The phosphate rock is heavy, weighing about 175 pounds to the cubic foot. Supposing workable phosphate rock 1 foot in thickness to underlie the 26,375 acres, there would be approximately 100,500,000 tons as an available supply in this territory, more than two and one-half times the amount estimated by the American Fertilizer. With the 3,000,000 tons of brown rock estimated, there would be a total available supply of 103,500,000 tons remaining in Tennessee. At the present rate of production in Tennessee this would last about 160 years. But with the exhaustion of the South Carolina and Florida deposits in twelve years the burden of the industry would fall on Tennessee and the western deposits. In case Tennessee furnished all the phosphates for the country, at the present rate of total production, 2,265,343 tons annually, after the South Carolina and Florida deposits are exhausted in twelve years, the Tennessee deposits would give out about 1960. These figures do not include vast quantities of rock running from 25 to 50 per cent lime phosphate, which are not at present workable.

Wyoming-Idaho-Utah.—The production from this field has not been sufficient to warrant mention, nor has enough detailed work been done in the area to afford a good basis for figuring available supply.

F. B. Weeks, of the Geological Survey, has made a reconnaissance report on the district, from which a very rough estimate of the available rock may be made. The phosphate formation consists of phosphatic limestones and shales 80 to 100 feet in thickness, varying in lime phosphate from 65 to 80 per cent in the workable beds to 20 to 50 per cent in the portion not at present workable. This series dips at all angles from 20° to 90°, thus giving a much larger possible tonnage than would be expected from the superficial extent of the deposits. The formation is cut by faults to a very great extent.

The area underlain by phosphate in the western field is almost wholly public land. Only one claim, the Waterloo placer claim, has been patented, but much land valuable for its phosphate deposits has been staked out in claims, of which there are not to exceed 200 in the aggregate. The engineer of the Waterloo property claims 1,000,000 tons of rock in sight above the valley, without taking into consideration the rock underground where the steep dip carries it from the mountain side. There are perhaps 200 other claims on which development work is being done at the present time. If each of these claims is but half as rich as is the Waterloo, they would represent an available supply of 100,000,000 tons in this field, a supply sufficient to furnish the entire production of the United States, based on the 1907 output, for forty-four years. It is to be understood that these figures do not include the immense quantities of low-grade rock which underlie the western field, nor do they take into consideration the quantities which are at present too deep to be profitably worked. With no more reliable figures at hand, this estimate is offered for the high-grade phosphate rock at present actually available in the Wyoming-Idaho-Utah field. Doubtless before the high-grade rock is exhausted some method will be devised for making use of the low-grade rock, which is at present unavailable both in Tennessee and the West.

Arkansas.—Phosphate deposits are known to occur in Arkansas, but they have not been mined to any large extent. They are apparently of low grade, and large quantities are not to be counted on until rock containing 30 to 50 per cent lime phosphate can be utilized for fertilizer manufacture. This material would not, therefore, be classed as available at this time.

EXPORTATION.

In 1907 there were 2,265,000 tons of phosphate rock produced in the United States. Of this amount over 900,000 tons, or about 40 per cent, was exported. It is not difficult to see that, with our steadily increasing population, the time is not very far distant when the farm lands of the Middle West will be burdened to their fullest capacity. It has been shown, as the result of agricultural experiment station work in Wisconsin, Ohio, and Illinois, that in fifty-four years soils of these States in the cropped areas have been depleted of one-third of their original phosphoric acid. This is equivalent to 20 pounds per acre annually. Assuming it to be only half this amount for the 400,000,000 acres of cropped land in the United States, it would require 6,000,000 tons of phosphate rock annually, or nearly three times our 1907 production, to offset this loss, without considering the question of increasing the productivity. With the reclamation of the arid lands of Wyoming and other Western States will come a period of intensive farming, and in order to produce the large crops which will be required of them, these lands must soon have the assistance of artificial fertilizer. We will have enough to do to take care of our own farm lands without shipping our phosphate rock to foreign countries, and in justice to future generations exportation should be stopped.

Total tonnage available.—Following is a table showing the estimated tonnage of phosphate rock available at the present time in the United States.

	Tons.
South Carolina	3,000,000
Florida	15,000,000
Tennessee	103,500,000
Western States	100,000,000
Total	221,500,000

ESTIMATED LIFE OF PHOSPHATE DEPOSITS.

The rate of increase in production for the past twenty years has been 117 per cent for each decade. Assuming that this rate of increase will continue, it will require just twenty-five years to exhaust the available supply of phosphate rock in the United States. The annual production, at the above rate of increase, will be approximately 17,000,000 tons in 1932.

It is hardly probable that the rate of increase in production will be so great as for the past decade, since the agricultural lands of the Middle West do not at present need artificial assistance. But increasing population with its accompanying intensive farming will eventually force these States to the use of fertilizing materials. The reclamation of arid lands in the West will probably postpone the day, but even those lands will early need some assistance to grow the large crops which will be required of them.

Of course the vast amount of low-grade rock which is not now available will be in reserve, and sometime before the exhaustion of the high-grade phosphates we will doubtless have begun to use this rock. The increasing price of the 60 to 80 per cent phosphate will have a hastening effect on the utilization of the present low-grade material. We have the deposits of Arkansas, Georgia, North Carolina, Alabama, Tennessee, and the West, which run from 30 to 50 per cent in lime phosphate, to draw upon after the high-grade rock is exhausted. This class of deposits, especially in Tennessee and the Western States, will afford an enormous tonnage.

There is still the chance of the discovery of more phosphate fields, and probably the Wyoming-Idaho-Utah field will produce far more than estimated, but based upon present available deposits the life of the phosphates must at best be a short one.

FOREIGN DEPOSITS.

Deposits of phosphate rock exist in Algeria, France, New Zealand, Canada, Russia, Spain, Tunis, Belgium, French Guiana, and some of the South Sea Islands. The deposits of France and Belgium are practically exhausted, only those of low grade remaining. Concerning the other countries, no information as to reserve tonnage is at hand except for the three South Sea Islands—Ocean, Pleasant, and Makatea. These islands have deposits which are estimated to contain an aggregate of 60,000,000 tons of high-grade phosphate rock.

UTILIZATION OF THE PHOSPHATES.

From the above figures it will at once be seen that the utilization of our phosphate deposits to the best possible advantage is imperative. Our farm lands must be preserved for future generations. The phosphate rock of South Carolina is practically exhausted; the Florida deposits have reached their maximum production; the output of the Tennessee deposits is on the increase, but this field alone would, at the present rate of increase in production, last only eleven years. There is some phosphate in Arkansas, but it is of low grade; therefore the large deposits of the public-land States must be depended on for the greater part of our phosphate in the future. The conservation of our phosphate deposits can be best accomplished in the following ways:

1. *Correction of wasteful mining methods.*—The waste involved in mining phosphates, especially in Tennessee, should have some attention. In order to get the largest quantity of high-grade rock necessary for the export trade, large amounts of 50 per cent rock are thrown on the dump and wasted. The time is sure to come when 50 per cent rock, and even 25 per cent rock, will be utilized in fertilizer manufacture. Steps should be taken now to prevent this waste in order to avoid a similar mistake when the phosphates of the Western States are mined. Much of the western rock runs from 25 to 50 per cent lime phosphate, and such material should be saved toward the time when the term "high-grade rock" will come to mean a lime phosphate content of 40 to 50 per cent instead of 70 to 80 per cent as at present.

2. *Utilization of sewage.*—One of the important sources of phosphoric acid to which we must look in the future is the human excrement which is now being wasted through the present systems of sewage disposal. Van Hise says:

> Whitson estimates that the loss in the cities due to man alone is the equivalent of 2 or 3 pounds of phosphoric acid per acre for the entire cropped region of the United States. Supposing this loss to be 2 pounds, this is one one-thousandth of a ton, which amounts for the 400,000,000 acres to 400,000 tons of phosphoric acid, or equivalent to 1,200,000 tons of phosphate rock.

The significance of these figures will at once be seen when it is known that the total production of phosphate rock in the United States for the year 1907 was 2,265,343 tons.

3. *Leasing of the phosphate deposits.*—Only by preventing or materially curtailing exportation can we be assured of the use of our phosphate deposits for our own lands in the future. The following table shows the production and exportation of phosphate since 1900:

Table showing production and exportation of phosphate rock in the United States, 1900–1907.

Year.	Production.	Exportation.	Year.	Production.	Exportation.
	Long tons.	*Long tons.*		*Long tons.*	*Long tons.*
1900	1,491,216	776,220	1905	1,947,190	879,979
1901	1,483,723	624,996	1906	2,080,957	964,241
1902	1,490,314	747,672	1907	2,265,343	900,983
1903	1,581,576	817,503			
1904	1,874,428	849,130	Total	14,214,747	6,560,724

From this table it will be seen that over 46 per cent of the phosphate rock produced in the United States since 1900 has gone to foreign countries. In this connection the American Fertilizer for November gives an account of the organization of the Franco-American Consolidated Phosphate Company, with a capitalization of $7,500,000. The capital stock is fully paid up, and is divided as follows: $5,250,000 for the purchase of phosphate lands in Tennessee, and $2,250,000 for the purchase of fertilizer plants in Europe and for working capital. The company is headed by a powerful syndicate of leading fertilizer manufacturers and bankers of France, Spain, Italy, and Belgium, who will control the stock of the company; and by this organization the fertilizer industry of Europe is expected to be completely under its control.

The company has purchased 16,375 acres of phosphate lands, and has 10,000 acres more under option. Among their plans it is stated:

> The company has contracted all of the export rock it can produce for the next ten years, and has concluded arrangements for the immediate introduction, on a large scale, of the blue rock, both in Europe and in this country.

From this it would appear certain that the phosphate deposits of the United States are to be drained for the benefit of the worn-out farm lands of foreign countries. So far as the deposits of Florida, Tennessee, and South Carolina are concerned, this can not be easily prevented, but the production of the newly opened western fields may be preserved for the United States by retaining in the Government title to all the phosphate rock in the lands now belonging to the United States, and leasing these deposits under appropriate terms.

In the lease could be included a clause providing that the lessee shall agree to mine phosphate rock only for home consumption.

If all the lands containing phosphate were reserved pending leasing, it would remove from entry certain lands which might otherwise be occupied by home seekers, and it is therefore necessary to provide for the disposal of surface rights alone. Such a separation of surface and mineral rights would obviate the necessity of creating large phosphate reserves in which the surface lands would be removed from settlement; it would permit the fullest utilization of the land in all particulars. A separation of surface and mineral rights would furthermore insure the proper utilization of all phosphate deposits which may hereafter be found in lands now belonging to the United States.

MINERAL RESOURCES OF ALASKA.

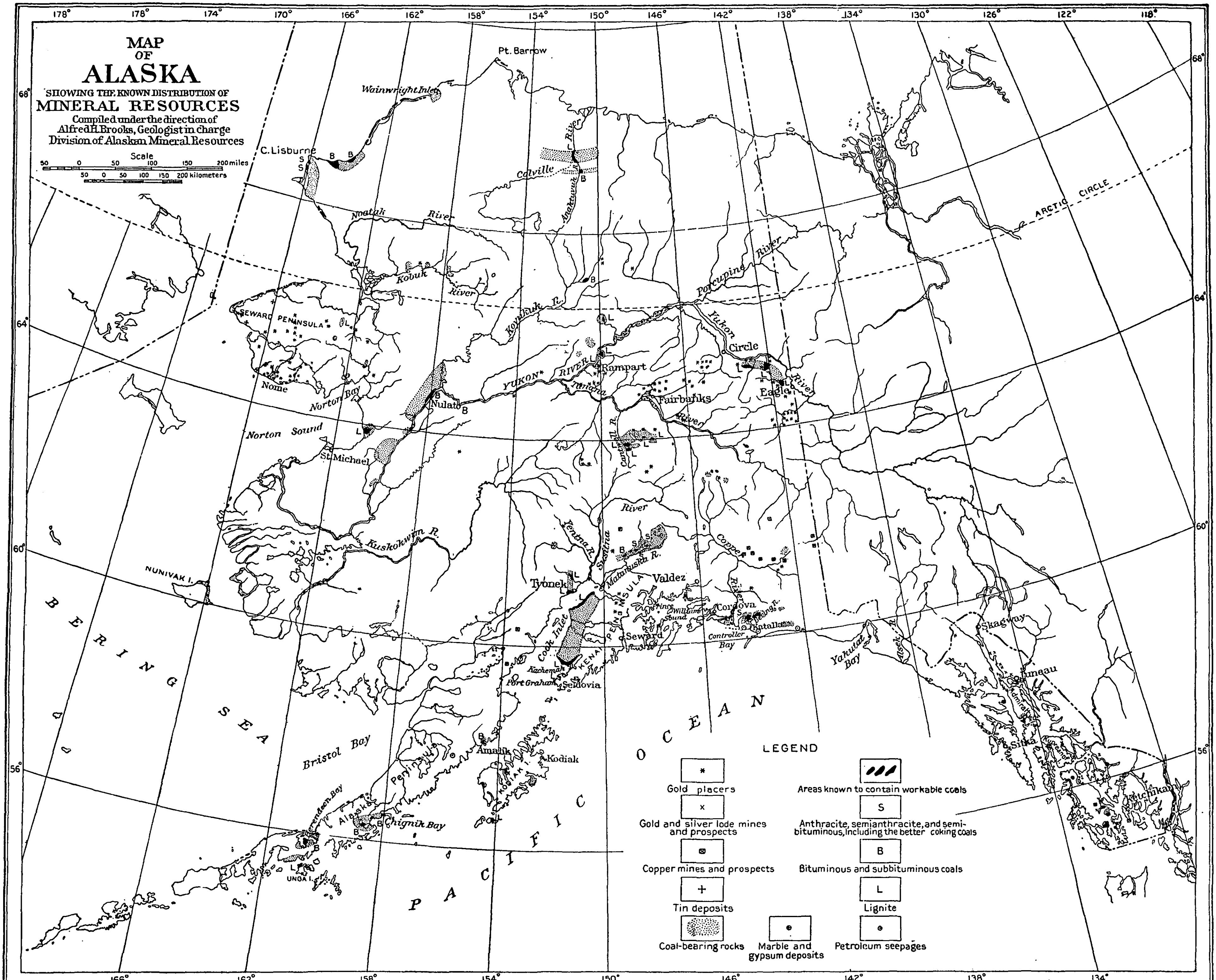
By Alfred H. Brooks.

INTRODUCTION.

A complete description of the mineral resources of any region is possible only when its geology has been exhaustively studied, and even then any quantitative determination of the mineral reserves is often little more than a bold guess. The Alaskan geologic surveys and investigations, begun a decade ago, now cover but 16 per cent of the entire Territory. These, moreover, for the most part have been of a preliminary character, and, while they have yielded important facts regarding the occurrence and distribution of the mineral deposits, they do not furnish the minute knowledge essential to quantitative determination. Detailed surveys and studies such as have been relied on elsewhere for quantitative data on mineral deposits are in Alaska almost entirely lacking, since less than a third of 1 per cent of its area has been subjected to such investigation. Therefore, as 84 per cent of the Territory is geologically almost unknown and less than 1 per cent has been mapped in detail, it will be evident that this statement can be only of a very general character.

The following account of the mineral resources of Alaska is based entirely on the work of the United States Geological Survey, whose reports furnish almost the only sources of information on this subject. In the preparation of this statement the writer has utilized the results of all the geologists and engineers who have worked in this field, and has received valuable assistance from G. C. Martin, C. W. Wright, L. M. Prindle, F. J. Katz, U. S. Grant, C. C. Covert, F. F. Henshaw, P. S. Smith, F. H. Moffit, W. W. Atwood, and Adolph Knopf.

In the lack of comprehensive quantitative data it will probably best serve the purposes of this report to consider the more general problems of geographic and geologic occurrence of the various useful minerals of the Territory. The coal resources will be considered at some length, both because of the importance of the mineral fuel reserves and because the geologic occurrence of coal is such as to permit a quantitative interpretation of the data with a far greater degree of assurance than of those relating to other mineral deposits. The subject of iron ore reserves, of almost equal importance with that


MAP OF ALASKA
SHOWING THE KNOWN DISTRIBUTION OF MINERAL RESOURCES
Compiled under the direction of Alfred H. Brooks, Geologist in charge Division of Alaskan Mineral Resources
Scale
50 0 50 100 150 200 miles
50 0 50 100 150 200 kilometers
LEGEND
Gold placers
Areas known to contain workable coals
Gold and silver lode mines and prospects
Anthracite, semianthracite, and semibituminous, including the better coking coals
Copper mines and prospects
Bituminous and subbituminous coals
Tin deposits
Lignite
Coal-bearing rocks
Marble and gypsum deposits
Petroleum seepages
Pt. Barrow
Wainwright Inlet
C. Lisburne
Colville
Noatak River
Kobuk River
Koyukuk R.
Porcupine River
Yukon
Circle
Rampart
YUKON RIVER
Tanana
Fairbanks
Eagle
SEWARD PENINSULA
Nome
Norton Bay
Nulato
Norton Sound
St. Michael
Kuskokwim R.
NUNIVAK I.
Yentna R.
Susitna
Matanuska R.
Copper River
Tyonek
Valdez
Cordova
Prince William Sound
Controller Bay
Katalla
Seward
KENAI PENINSULA
Cook Inlet
Kachemak
Port Graham
Seldovia
Yakutat Bay
Skagway
Juneau
Sitka
Ketchikan
Bristol Bay
Amalik
Kodiak
KODIAK I.
Alaska Peninsula
Chignik Bay
UNGA I.
BERING SEA
PACIFIC OCEAN
ARCTIC CIRCLE

of coal, can be but briefly touched upon, because so few facts regarding it are available. But little attention has been devoted to iron ore by the Alaskan geologists, for there is not a single iron mine in the Territory and at only two localities have iron-ore bodies been prospected. Relatively much more is known about the auriferous deposits, especially the placers, for here the observation of the geologist is supplemented by the many facts developed in the course of mining and prospecting. But the character of these deposits, especially that of the auriferous lodes, makes estimates of mineral reserves of but little value. The same holds true of the copper deposits, which are of too great irregularity to allow even an approximation of the available tonnage. Moreover, though copper ores find a wide distribution in the Territory, they have been mined in only two districts. Most of the copper mines are not over 200 feet in depth, one only having reached 600 feet. Predictions as to permanency of ore bodies at depth in this field, which must form an important element in estimating tonnage, can therefore have no great value.

GENERAL DISTRIBUTION.

The ores and other minerals mined in Alaska up to the close of the year 1907 include gold, silver, copper, lead, tin, coal, petroleum, gypsum, marble, and mineral waters. In addition to these iron, tungsten, antimony, quicksilver, graphite, and peat have been found in deposits that will probably be exploited in the future. Of these only the deposits of gold, silver, copper, lead, iron, coal, petroleum, and peat will be described in this report.

As there are no political subdivisions of Alaska, it will be desirable to refer the distribution of its resources to certain geographic provinces, and these must first be defined. (See Pl. XII.) The Pacific province includes the lode and placer districts of southeastern Alaska, the Controller Bay coal and petroleum fields, the copper lodes of Prince William Sound, the copper-bearing lodes and gold placers of the Copper River region, the gold placers and lodes and coal fields of the Susitna and Matanuska basins and of the Kenai Peninsula, and the coal fields and gold and copper lodes of the Alaska Peninsula and adjacent islands, often called southwestern Alaska. This whole coast province is a region of strong relief, and much of it is readily accessible from the waters of the Pacific, open to navigation throughout the year.

The mountain system included within the Pacific province forms a high barrier between the coast and the central province, which is of lesser relief. This central province, drained to Bering Sea by the Yukon, Kuskokwim, and some smaller rivers, includes the gold placers of the Yukon-Tanana region, the Koyukuk, and some smaller districts, as well as extensive deposits of lignitic coal. It is accessible in summer by river steamers, but in winter only by long sled journeys.

Seward Peninsula, forming a distinct province, embraces valuable gold placers, as well as some auriferous and argentiferous lodes, some tin deposits, and a little lignitic coal. It is accessible by steamer only during the summer months.

Northern Alaska is here made to include the high mountains which bound the central province on the north, as well as the region of lesser relief bordering the Arctic Ocean. This field has been but little explored, but it is known to contain some placer gold and bituminous as well as lignitic coal. It seems probable that further surveys will show the presence of extensive coal fields in northern Alaska.

These geographic subdivisions have an important influence on the question of the conservation of the mineral wealth of the Territory, for as the geographic conditions dominate the commercial exploitation of the resources, they determine in a large measure the rapidity with which these resources will become exhausted. For example, the lode deposits and coal fields readily accessible from the Pacific seaboard are being exploited for the use of the present generation. On the other hand, though the development of the placer fields of the central province began nearly a generation ago, large areas are still entirely unprospected, and the coal fields of the same region are almost entirely untouched. The coal fields of northern Alaska are not only entirely undeveloped, but are certain to remain so until the time in the future when the accessible coal of Alaska and the United States approaches exhaustion.

COAL.

By Alfred H. Brooks and George C. Martin.

STRATIGRAPHIC POSITION AND COMPOSITION.

The Alaskan coals include lignitic, bituminous (some of which will make good coke), and anthracite varieties. Of these the lignitic and lower-grade bituminous coals are the most widely distributed and, so far as now known, the most abundant, at least half of the known coals being lignites. To offset their lower fuel value the lignites often occur in thick beds and with a large percentage of coal in any given section. Moreover, their geographic distribution is such that they afford an important source of fuel for local consumption in some of the less accessible parts of the Territory.

These coals belong to four geologic periods, namely, Tertiary, Cretaceous, Jurassic, and Carboniferous. In addition to these there are some inferior lignites of Quaternary age, and it is by no means improbable that further investigation may lead to the discovery of coal at still other horizons. Of these four periods only the fuels of the first three promise to have any considerable commercial importance, and all but one of the important coal fields are of Upper

Cretaceous or Tertiary age. In fact, a large part of the coal beds have been identified as belonging to the Kenai formation, whose age is believed to be upper Eocene. The Carboniferous and Jurassic coals vary in composition from semibituminous to subbituminous fuel. In the younger coal fields anthracite, various grades of bituminous, and lignitic coals are found.

The following table shows the composition of the coals from different parts of the Territory:

Analyses of Alaska coal.

[Compiled from reports of United States Geological Survey.]

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
ANTHRACITE.						
1. Bering River, average of 7 analyses	7.88	6.15	78.23	7.74	1.30	12.86
2. Matanuska River, 1 sample	2.55	7.08	84.32	6.05	.57	11.90
SEMIANTHRACITE.						
3. Bering River, average of 11 analyses	5.80	8.87	76.06	9.27	1.08	8.77
SEMIBITUMINOUS.						
4. Bering River, coking coal, average of 28 analyses	4.18	14.00	72.42	9.39	1.73	5.28
5. Cape Lisburne, average of 3 analyses	3.66	17.47	75.95	2.92	.96	4.46
6. Matanuska River, coking coal, average of 16 analyses	2.71	20.23	65.39	11.60	.57	3.23
BITUMINOUS.						
7. Lower Yukon, average of 11 analyses	4.68	31.14	56.62	7.56	.48	1.90
SUBBITUMINOUS.						
8. Matanuska River, average of 4 analyses	6.56	35.43	49.44	8.57	.37	1.40
9. Koyukuk River, 1 sample	4.47	34.32	48.26	12.95	....	1.40
10. Nation River, 1 sample	1.39	40.02	55.55	3.04	2.98	1.39
11. Alaska Peninsula, average of 5 analyses	2.34	38.68	49.75	9.22	1.07	1.30
12. Cape Lisburne, average of 11 analyses	9.35	38.01	47.19	5.45	.35	1.24
13. Anaktuvuk River, 1 sample	6.85	36.39	43.38	13.38	.54	1.20
LIGNITE.						
14. Port Graham, 1 sample	16.87	37.48	39.12	6.53	.39	1.04
15. Southeastern Alaska, average of 5 samples	1.97	37.84	35.18	24.23	.57	1.02
16. Wainwright Inlet, 1 sample	10.65	42.99	42.94	3.42	.62	1.00
17. Colville River, 1 sample	11.50	30.33	30.27	27.90	.50	1.00
18. Upper Yukon, Canadian, average of 13 analyses	13.08	39.88	39.28	7.72	1.26	.99
19. Upper Yukon, Circle province, average of 3 analyses	10.45	41.81	40.49	7.27	1.30	.97
20. Upper Yukon, Rampart province, average of 6 analyses	11.42	41.15	36.95	10.48	.33	.91
21. Seward Peninsula, 1 sample	24.92	38.15	33.58	3.35	.68	.88
22. Chitistone River, 1 sample	1.65	51.50	40.75	6.10	....	.79
23. Kachemak Bay, average of 6 analyses	19.85	40.48	30.99	8.68	.35	.77
24. Nenana River, 1 sample	13.02	48.81	32.40	5.77	.16	.66
25. Kodiak Island, 1 sample	12.31	51.48	33.80	2.41	.17	.66
26. Unga Island, average of 2 analyses	10.92	53.36	28.25	7.47	1.36	.62
27. Tyonek, average of 4 analyses	8.35	54.20	30.92	6.53	.38	.58
28. Chistochina River, 1 sample	15.91	60.35	19.46	4.28	....	.32

DISTRIBUTION AND AREA.

The known coal-bearing areas aggregate some 1,202 square miles, while the estimated areas of the coal fields are 12,667 square miles (see p. 182). The distribution of the coal, together with a symbol indicating its quality, is shown on Plate XII.

Besides showing the actual distribution of the areas believed to be underlain by workable coal beds (marked in black) the map also shows the areas of the coal fields, so far as they are known (marked by stippling). The difference in what is represented by these two symbols is that in the first are included areas in which there is a reasonable degree of certainty that commercial coal beds can be opened up, while the second indicates what is known of the probable extension of the coal fields, and hence defines the areas worthy of prospecting. It should be noted that this mapping does not by any means have the same value throughout the territory, for in some instances it is based on geologic surveys of a high degree of refinement; in others the data include only observations made during a rapid reconnaissance.

The coal fields can be considered under the three general geographic provinces already described: (1) The Pacific slope, (2) the central region, and (3) the northern. (See Pl. XII.) In the first are included the lignitic and bituminous fields of southeastern Alaska, Cook Inlet, the Susitna Basin, and the Alaska Peninsula, as well as the high-grade fuels of the Controller Bay and Matanuska regions. About 40 per cent, both of the area known to be underlain by coal and of the estimated area of the total coal fields of the Territory, falls in this province. It includes also at least 90 per cent of the known bituminous and higher-grade coals of the Territory. In considering this percentage of total coal area it must be remembered that this is the best-known part of the Territory, and there is, therefore, less likelihood of future discoveries of coal than in the less explored districts of central and northern Alaska. However, as over 50 per cent of this province is geologically almost unknown, there are possibilities that future surveys may lead to the discovery of more extensive coal-bearing areas.

The central province includes some bituminous and subbituminous coals on the lower Yukon, besides more extensive lignitic coal-bearing fields in the upper Yukon basin, near the coast line of Bering Sea, and elsewhere. Thirty-five per cent of the total known coal-bearing area falls in this province, and about 36 per cent of the estimated coal fields. At least 80 per cent of the central province, however, is almost unknown, so it is likely that further discoveries of coal will there be made.

The northern region includes the bituminous and subbituminous coals of the Cape Lisburne region, as well as lignitic and bituminous coal-bearing rocks in the Colville basin. These fields aggregate 24 per cent of the coal area of the Territory, and the area known to be underlain by coal forms 25 per cent of the total. This is a remarkable showing, in view of the fact that only about 10 per cent of this province has been studied geologically. There is every reason to believe that there are extensive coal fields in this part of Alaska.

THE COAL FIELDS.

SOUTHEASTERN ALASKA.

Though Tertiary (or possibly Upper Cretaceous) coal-bearing rocks are known to cover a considerable area on the southern part of Admiralty Island and on adjacent islands, the included coal beds have only a remote fuel value. The beds are from a few inches to 2 or 3 feet in thickness, and the coal, so far as known, is of a low-grade lignitic character.

BERING RIVER.

One of the two fields containing the largest known amount of high-grade coal lies about 25 miles northeast of the small indentation of the southern shore line of Alaska called Controller Bay. The field is drained by Bering River, from which it received its name. This Bering River field embraces 21.6 square miles underlain by anthracite and 22.7 square miles underlain by semibituminous and semianthracite coal. The coal-bearing rocks trend to the northeast into the unsurveyed high ranges, and it is quite probable that there are considerable areas in the unsurveyed extension of the coal field or possibly other coal fields beyond the one surveyed.

The workable coal beds in this field vary from 6 to 25 feet in thickness, though local swellings occur, giving a much higher maximum. They are included in a great series of sandstones and shale of Tertiary age (Miocene?) which are closely folded and faulted. In quality the coals vary from an anthracite, with 84 per cent of fixed carbon, to a semibituminous, with 72 per cent of fixed carbon (see p. 175). The field includes some coking coal. There is no good harbor at Controller Bay, though plans have been made for building a breakwater. Another scheme of obtaining access to the coal is by constructing a railway from Cordova Bay, a good harbor lying 100 miles to the west. This railway is now (1908) about half completed.

COOK INLET.

Lignite-bearing Tertiary rocks occur widely distributed in the Cook Inlet region. These are usually little disturbed, but locally are considerably folded and faulted. The largest areas of coal-bearing rocks in this field occupy the western part of the Kenai Peninsula and are in part buried under a cover of Quaternary gravels. It is not impossible that the entire Cook Inlet depression may be underlain by the coal-bearing formations.

The best-known part of this field lies adjacent to Kachemak Bay on the north, where 2,000 to 3,000 feet of coal-bearing rocks are exposed. These contain an aggregate thickness of over 60 feet of workable coal beds, the thickest of which is about 7 feet. Lignite in workable seams has also been found at Port Graham and Tyonek.

Though the Kenai Peninsula was the scene of the earliest (1854) coal-mining venture in Alaska, the output has been only a few thousand tons. These coals, in spite of their accessibility to tide water, can probably not compete with the higher-grade fuels, such as those of the Matanuska field. It seems probable that the coal reserves in the Cook Inlet region are very large, for the area of the coal field is estimated at 2,565 square miles.

MATANUSKA REGION.

The Matanuska coal field shares with that of Bering River the preeminence in the present fuel situation in the Territory. This field lies about 25 miles from tide water at Knik Arm, a northerly embayment of Cook Inlet. As, however, Cook Inlet is frozen during the winter months, the distance to tide water must be measured to the eastern side of Kenai Peninsula, about 150 miles.

The known commercially valuable coals of the Matanuska are included in folded and faulted rocks of Tertiary (Eocene?) age, including shales, sandstones, and conglomerates aggregating 3,000 feet in thickness. The coal-bearing series has been traced for 50 to 60 miles along the Matanuska Valley, but much of it is buried under a heavy blanket of Quaternary gravels. At the western end of the district the bituminous coal, which seems to form the main body of the field, appears to pass into a lignite, while there is some evidence that the same coal is represented by an anthracite at the eastern end of the belt. This anthracite may, however, belong to an older coal-bearing formation.

The commercial coals of the Matanuska field vary from a subbituminous to a semibituminous. There is also some anthracite, but of this less is known. It is evident from the facts in hand that there is a large amount of high-grade bituminous coal in this district. The beds vary from 5 to 30 feet in thickness.

So far as at present known, the total area underlain by commercial seams aggregates 46.5 square miles. As, however, much of the field is covered by gravels and as it has not been surveyed in detail, the coal-bearing area may be much larger. The total area of what may prove to be coal-bearing rocks is approximated at 900 square miles.

A railway is under construction which will lead to the opening of this field. This will bring about the development of the high-grade fuels, of which there is a large quantity. The lignites lying to the west of the Matanuska field will not now bear shipment until the coals of the higher fuel value approach exhaustion. As there is believed to be a very large amount of lignitic coal in this general province, it will be an important element of the ultimate fuel reserves of the Territory.

ALASKA PENINSULA REGION.

The widely distributed coal of the Alaska Peninsula and adjacent islands is in part of Cretaceous and in part of Tertiary (Eocene) age. It is chiefly lignite, but some good bituminous coals occur in this field. The rocks in which the coal beds occur are gently folded and locally, at least, considerably faulted. The total area of the coal fields of this province is estimated at 980 square miles, while that known to be underlain by coal is 61 square miles. About one-half of the coal-bearing area and about one-third of the probable coal field is lignitic, the balance varying from subbituminous to bituminous in quality. Coal has been mined in this field at Chignik and Herendeen bays and on the island of Unga for local use, but the total output has been only a few thousand tons. These coal fields are all readily accessible from good harbors and will form one of the early available fuel assets of the Territory when the demand for coals of this grade warrants their exploitation.

YUKON REGION.

The coals of the Yukon, including bituminous and subbituminous, together with a large amount of lignite, are for the most part of Tertiary (Eocene?) age. Some of the bituminous may, however, be of Upper Cretaceous age. The Tertiary lignitic coal beds typically occur in association with conglomerates, sandstones, and shales, usually only little deformed, but sometimes profoundly folded and faulted. The bituminous coals, which are confined to the lower Yukon, occur with finer sediments, which have been gently folded and somewhat faulted.

The lignitic coal beds occur up to 20 feet in thickness, the bituminous in beds from 2 to 3 feet. These comparatively thin seams have not encouraged exploitation, in spite of the high price of mineral fuel in this central region, but a small production has been made for the use of the Yukon River steamers.

Coal-bearing beds are so widely distributed in the Yukon region that it will not be feasible to give an account of all the occurrences. The three largest fields are (1) Nulato region, (2) Nenana region of the lower Tanana Valley, (3) Washington and Coal Creek belt of the upper Yukon. Of these the Nulato field contains the best coal, while the Nenana is the most extensive and has the thickest beds. The total area known to be underlain by coal in the entire region is 264 square miles, while the coal fields may embrace 2,000 square miles or more.

These Yukon coals will have a high value for local use when the scant supply of accessible timber has been exhausted. There is a constantly increasing demand for power in the placer districts, and this can be met only by developing the water powers, which are not extensive, or by utilizing the coals. The low fuel values and the difficulties of transportation of these coals will probably lead to their local transformation into electric power, to be transmitted to the mining camps. The location of some of the lignite fields with reference to the placer fields is well suited for this purpose.

That a large amount of lignite in excess of any future local demand that can now be foreseen occurs in the Yukon region can not be denied. So far as exportation is concerned, it is certain that the low fuel value of these coals and their inaccessibility will lead to their conservation until the fuel supply of other regions approaches exhaustion.

SEWARD PENINSULA.

The known coal-bearing areas of Seward Peninsula do not exceed a few square miles, and the quality of the coal is of a low grade. This coal, however, is worthy of mention, because it can probably be locally utilized to furnish power for mining purposes, and hence conserve the higher-grade coals which are now being brought in from outside sources. This appears to be a good example of the way a local supply of lignite may reduce the consumption of higher grade fuels. Its success will depend on the development of economical means of utilization of these low-grade fuels, so as to bring them within the sphere of commercial practice and permit their substitution for higher-grade fuels transported from a distance.

NORTHERN ALASKA.

Geographically, the known coal fields of northern Alaska fall into three groups: (1) Cape Lisburne, (2) the Colville Valley, (3) Wainwright Inlet. Coal has also been reported to occur between these areas, as well as east of the Colville River. The Cape Lisburne field includes the Corwin and Cape Beaufort districts.

Three coal-bearing formations are recognized in this northern field: (1) lower Carboniferous (Lisburne formation), made up of slates, shales, and limestones, with some high-grade bituminous coals, and having a thickness of 500+ feet; (2) Jurassic (Corwin formation), including at least 15,000 feet of shales, sandstones, and conglomerates and containing a large number of subbituminous coal beds; (3) Tertiary (Kenai formation?), made up of conglomerates, sandstones, and shales, with lignitic coal seams. The two lower formations are considerably folded, but the Tertiary beds are, as a rule, only little disturbed.

The total area known to be underlain by coal aggregates 302 square miles, while the coal fields, roughly outlined from the data in hand, include some 3,000 square miles. The scant evidence at hand points to the conclusion that a survey of this northern region will show very large coal fields in this part of Alaska.

A little mining of coal for local use has been done in the bituminous field near Cape Lisburne and in the lignitic field of Wainwright Inlet, but the region as a whole is practically untouched. It is certain that there will be no extensive mining in this northern field for a generation or two to come. These coals are too inaccessible to invite exploration, either under the present demands or any that can now be foreseen.

THE COAL RESERVES.

INTRODUCTION.

It will be evident from the facts presented that there are few data on which even an approximate idea of the available tonnage of Alaskan coal can be based. Of the 1,238 square miles believed to be underlain by coal, less than one-quarter has been surveyed in sufficient detail to yield any quantitative data whatever. Even where such surveys have been made, a large factor of uncertainty is introduced either by the folded and faulted condition of the coal beds, which exists in some fields, or by the lack of definite knowledge of the continuity of the coal beds in others. There must, therefore, be a very large element of uncertainty in the tonnage estimates of the 300 to 400 square miles of surveyed coal fields. Moreover, in Alaska there are practically no available data from private sources, such as the results of extensive mining or prospecting operations, which have formed an important element in the estimates made of the mineral resources in the States.

The estimates of tonnage to follow were made on the following basis:

1. No beds less than 3 feet thick were assumed to be workable or to contribute to the tonnage.

2. The depth of workability was assumed to be 3,000 feet in the case of the highest-grade coal (anthracite, semianthracite, semibituminous), 2,000 feet in case of the better bituminous and subbituminous coals, such as those on the lower Yukon and at Cape Lisburne and on the Matanuska River, and 1,000 feet in the case of the poorer subbituminous and all the lignites.

3. The tonnage was computed by the following formula: Tonnage = area of bed to limit of workability (square miles) $\times$ thickness (inches) $\times$ sp. gr. $\times$ 72,600.

4. The specific gravity was assumed to be 1.30 for lignite, 1.35 for bituminous, and 1.38 for the high-grade coals.

5. Bering River field: A certain percentage of the coal-bearing rocks is shown by the average sections to consist of workable coal beds. This percentage of the computed bulk of rock to limit of workability gave the estimated tonnage.

6. Nenana coal field: As for Bering River, with the necessary change for percentage of coal in rocks.

7. Matanuska coal field: Each bed was estimated separately according to its average thickness, length according to a safe assumption of continuity, and width on the dip to the limit of workable depth.

8. Lisburne fields: The Corwin district was computed like the Matanuska, length of beds being assumed to be the distance from the shore to the edge of the area colored on Collier's map. The Beaufort district was assumed to have one-half the tonnage per square mile of the Corwin district.

9. Yukon field: Each bed figured as in Matanuska, but the beds were not assumed to extend in any case more than 1 mile in each direction from the mine or prospect where they had been exposed, except in the Washington-Bonanza district, where a continuity of 50 miles on the strike was assumed.

10. Cook Inlet field: Computed as for the Matanuska.

All the other fields were estimated on the basis of a most conservative estimate of thickness of coal underlying the field and an area believed to be a safe minimum. Neither in this case nor in any of the others was the coal assumed to go beyond where we have reliable information from members of the Survey concerning it. The areas used in making the last class of estimates are consequently very small and are subject to a possible immense extension in the light of subsequent work.

Estimate of tonnage and areas, Alaska coal fields.

	Tonnage.	Areas believed to be underlain by coal.	Supposed areas of coal fields.
	Short tons.	*Sq. miles.*	*Sq. miles.*
Anthracite, Pacific coast	1,611,700,000	25.8	....
Semianthracite, Pacific coast	517,100,000	7.2	....
Semibituminous:			
Pacific coast	1,425,800,000	35.8	....
Arctic slope	66,800,000	14.2	....
Total semibituminous	1,492,600,000	50.0	....
Total high-grade	3,621,400,000	83.0	620
Bituminous:			
Pacific coast	2,600,000	2.0	900
Interior region	15,900,000	162.0	2,475
Total bituminous	18,500,000	164.0	3,375
Subbituminous:			
Paific coast	535,500,000	49.7	657
Interior region	59,200,000	6.0	15
Arcctic slope	3,465,600,000	205.0	1,323
Total subbituminous	4,060,300,000	260.7	1,995
Lignite:			
Pacific coast	2,173,100,000	337.0	2,938
Interior region	4,228,000,000	264.5	2,003
Arctic slope	1,003,200,000	93.0	1,736
Total lignite	7,404,300,000	694.5	6,677
Summary by provinces:			
Pacific coast	6,265,800,000	457.5	5,115
Interior region	4,303,100,000	432.5	4,493
Arctic slope	4,535,600,000	312.2	3,059
Grand total	15,104,500,000	1,202.2	12,667

The incompleteness of these figures can best be illustrated by some examples. The Bering River field may be extended into the mountains and have many times its present known area. If the entire eastern and western extensions of the Matanuska Valley are underlain by coal beds, as may be the case, it will increase the tonnage of this field many times that used in the present estimate. In the Cook Inlet and Susitna regions the estimates for tonnage are based on a coal field of 30 to 40 square miles. As a matter of fact, it is not improbable that the whole Cook Inlet-Susitna depression may be underlain by coal-bearing rocks at no depth prohibitive of mining. If this is the case, this coal field might embrace 10,000 to 20,000 square miles.

In view of these facts, it is perhaps conservative to multiply the above figures by 10 or even by 100 to arrive at an approximation of the fuel reserves of this vast unexplored region. This is especially true of the lignite reserves, for there are known to be very extensive fields of low-grade coals in Alaska.

PRODUCTION AND CONSUMPTION.

Though an attempt at mining coal on Cook Inlet in 1854 by the Russians was the first mining undertaken in the Territory, yet the total output up to the present time has been very small, as indicated in the following table. In 1907 there were four productive coal mines in Alaska.

Production of coal in Alaska, 1888–1907.

Year.	Short tons.	Value.	Year.	Short tons.	Value.
1888–1896 [a]	6,000	$84,000	1903	1,447	$9,782
1897	2,000	28,000	1904	1,694	7,225
1898	1,000	14,000	1905	3,774	13,250
1899	1,200	16,800	1906	5,541	17,974
1900	1,200	16,800	1907	10,139	53,600
1901	1,300	15,600			
1902	2,212	19,048	Total	37,507	296,079

[a] The production for 1888–1896 is estimated on the best data obtainable. That for the years subsequent to 1896 is based for the most part on data supplied by operators.

The smallness of the output is chiefly due to two reasons: First, because up to a decade ago, when the rapid advancement of the gold-mining industry began, the local demand for coal was very small, being confined to that of the canneries and shipping interests and the Treadwell mine, which could be supplied at low cost by the fuels brought from Vancouver Island or Washington. Second, the existence of extensive bodies of high-grade coal in Alaska, geographically situated so that it could be exported, has been generally known only for a few years. Since the discovery and surveys of the Controller Bay and Matanuska regions there has been much activity looking to the development of these two fields. As, however, the marketing of this coal requires the construction of 150 miles of railway in one field and 100 miles of railway or 25 miles of railway and possibly an expensive breakwater in the other, the progress of exploitation is necessarily slow. Moreover, the uncertainty of obtaining title to coal lands, which still exists, has made capitalists rather guarded in furnishing the money necessary for these enterprises.

Though the Territory has produced annually only a few thousand tons, the consumption of coal during the past decade has rapidly increased. The following table presents the available statistics regarding consumption of mineral fuels in Alaska:

Shipments of coal and coke to Alaska, July 1, 1903, to June 30, 1907.[a]

	Twelve months ending June 30—							
	1904.		1905.		1906.		1907.	
	Quantity.	Value.[b]	Quantity.	Value.[b]	Quantity.	Value.[b]	Quantity.	Value.[b]
	Long tons.		*Long tons.*		*Long tons.*		*Long tons.*	
Domestic anthracite	....	....	5	$85	....	....	476	$7,090
Domestic bituminous	41,704	$193,740	42,245	187,352	67,293	$265,047	48,383	270,651
Domestic coke	392	2,251	478	4,281	346	3,676	3,108	25,629
Foreign anthracite	....	....	10	148	304	1,836	25	216
Canadian bituminous	63,652	261,987	59,272	260,110	41,481	187,312	64,029	287,948
Australian bituminous	1,609	4,303	....	....	....	....	3,529	8,587
Japanese bituminous	....	....	....	....	....	....	11,546	33,789
Foreign bituminous, shipped via United States	3,324	23,904	5,550	29,673	706	4,838	4,141	28,679
Foreign coke	....	....	....	....	7,628	38,139	2,959	14,795
Total	110,681	486,185	107,580	481,657	117,758	500,848	138,196	677,384

[a] Commerce of the noncontiguous territory of the United States, Bureau of Statistics, 1904, 1905, 1906, 1907.
[b] At port of shipment.

Shipments of petroleum to Alaska.[a]

Period.	Crude petroleum.			Naphthas.	
	Gallons.	Barrels.	Value.	Gallons.	Value.
Six months ending—					
December, 1902	21,000	500	$390	60,358	$12,186
June, 1903	840,000	20,000	28,000	210,147	33,831
December, 1903	1,008,000	24,000	36,000	84,776	18,054
June, 1904	1,008,400	24,010	35,823	231,658	43,814
December, 1904	1,008,030	24,001	33,603	106,623	23,904
June, 1905	1,780,326	42,389	59,204	499,196	75,187
December, 1905	935,060	22,263	31,864	214,300	34,734
June, 1906	1,428,000	34,002	20,400	361,681	60,214
December, 1906	1,260,100	30,000	18,009	219,297	40,480
June, 1907	2,545,200	60,600	36,360	354,210	59,012
December, 1907	6,558,500	156,155	107,146	282,671	60,333
June, 1908	3,852,940	91,736	55,482	599,959	91,084

[a] Monthly Summary of Commerce and Finance, Bureau of Statistics, 1902–1906.

SUMMARY AND CONCLUSIONS.

The advancement of copper and gold mining, construction of railways, etc., will cause a constantly increasing consumption of coal. It would appear to be in accord with a policy of conservation of mineral fuels to meet this demand from the local supply. Every ton of coal or barrel of petroleum shipped to Alaska by steamer or rail entails a certain amount of fuel consumption for transportation. Moreover, this long carriage is commercially possible only for high-grade fuels, while for local consumption the large supply of lignites of lesser fuel value can be utilized. For example, many of the Alaskan river steamers, now using California petroleum as fuel, could be supplied by the local lignites. This would prevent a double waste: (1) The more valuable fuel is consumed instead of the more abundant lignite, and (2) as the petroleum is brought nearly 4,000 miles by steamer, fuel is used for its transportation. The utilizing of the coals in the Yukon region as a substitute for wood would also conserve the scant supply of timber.

Again, the use of the local coking coals for the reduction of the copper ores will effect a saving of mineral fuels. At present the copper ore is shipped a distance of 500 to 1,500 miles, while if it were smelted near its locality of production 70 to 90 per cent of the material could be left behind, with a corresponding saving of fuel used in transportation. Another saving would be brought about in the case of Alaska steamers now carrying coal from the southern ports for the round trip, if the local fuels were utilized for the return journey.

Discussion of the future utilization and conservation of Alaska's coal supply can best be made by considering separately the same three geographic provinces under which the coal fields have been described: (1) The Pacific slope, (2) the central regions, (3) the northern region. These will here be considered in the reverse order in which they have been given.

The northern coal fields lie in a region tributary to the Arctic Ocean, which is locked in the ice for all but two or three months in the year. Some lie close to the seaboard; others far inland. While little is known of the fuels of this region, all the facts available point to the conclusion that this province contains very extensive coal fields. These mineral fuels are in a region where there are practically no industries and little promise that any will be developed, and the coals are unavailable until the more accessible mineral fuel supply of the world approaches exhaustion. To bring them to a harbor open throughout the year would mean the construction of at least 1,000 miles of railway. Such a haulage, leaving out all other considerations, is of course prohibitive for any present fuel demand. Moreover, these coals are not needed, nor likely ever to be, for any local use, except some of those at Cape Lisburne, which may be utilized for local shipping, and some others which may be used by the scant Eskimo population, now that the supply of driftwood is approaching exhaustion.

The fuels of this northern region can, therefore, be regarded as conserved by the geographic conditions until future generations may have to draw upon them. They can consequently, for the most part, without injury to any existing commercial interests and without retarding the development of the country, be placed under such legislative provisions as will permit their utilization only under such restrictions as the future conditions of the mining industry shall demand.

The coals of the central region are in part accessible to rivers navigable during the summer months and in part lie near the proposed railways from the Pacific to the Yukon. There also remains a considerable percentage but little more available to the present generation than the fuels of the northern fields. These coals are chiefly lignitic in character and, under no demand which can now be foreseen, could be utilized for export to other districts. To bring them to the States would require a railway haulage of 400 to 500 miles and then transportation by steamer for 1,000 to 1,500 miles in addition.

On the other hand, the development of these fields to supply the local demand will conserve (1) higher-grade fuels now imported from great distances and (2) local supply of timber. While little is known of the amount of coal available in this central province, there is every reason to believe that it is far beyond any local demand of the future.

The conservation of the coal of the Pacific slope province is a more complex problem, both because of the high grade of some of the fuels and of their greater accessibility. While none has yet been exported, the great demand for the high-grade bituminous and anthracite coals, such as are found in the Controller Bay and Matanuska regions along the Pacific coast, will lead to their exportation as soon as railways make them accessible. It is probable that the market for these coals will for a long time exceed the production, which will greatly stimulate mining activity once the transportation problem has been solved. When the coals are put on the market, they will probably curtail, if not entirely cut off, the demand for the lignitic and lower-grade bituminous coals which are so abundant in the Pacific coast province of Alaska. Therefore the production of the high-grade fuels will effectually conserve those of lesser fuel value for the present. Some of these low-grade fuels, however, are so accessible and so abundant that future demands and strong competition may lead to wasteful methods of mining, provided they are all permitted to pass into unrestricted private ownership.

The reserve of these anthracite and bituminous coals of the Pacific slope, while it can not now even be approximated, in all probability is far below that of the lignites. It seems probable that an extensive area of the high-grade fuels may be found among the high mountains and glaciers to the northeast of the present known limits of the Bering River field. If such be the case, this will be another locality where the geographic conditions will prevent mining until there is far more demand for the fuel than at present. In the Matanuska there is probably also a large quantity of coal under the Quaternary coating of gravel. Making allowances for future discoveries, however, the high-grade fuel is not abundant, considering the demand for it.

From the standpoint of conservation and economic utilization, the possibility of intense competition between the coal of the Bering and Matanuska fields and that of Puget Sound is the danger point in the prospective situation. If each field develops only to the extent of supplying the demand for the kind of coal which it best can furnish, then the immediate use of the coal will be legitimate and economical. But if the individual fields develop beyond the demand of their respective proper markets—if the Bering River field produces more than the needed supply for steamship, smithing, and local railway and smelting needs and of domestic anthracite, if the Matanuska produces more than is needed for its local railways and smelters, for bunker coal at its tidal terminus, and for shipment to the Pacific coast coke ovens, and if the coal from other fields invade these markets—there is sure to be ruinous competition, which may lead to cutting prices with the sole object of destroying all competition and establishing a general monopoly. In such ruinous competition as has existed in some of the eastern fields the coal fields will be robbed of the more cheaply minable coal at the cost of the destruction of larger amounts which will be left in the ground so crushed and buried that it can never be recovered, coke for distant shipment will be made by wasteful processes at the mines instead of shipping the coal to points where both the coke and the by-products can be used, coal will be coked which would better be used for other purposes, and the waste by consumption en route will be extended to the Alaska coals.

If these high-grade fuels, some of which make excellent coke, are not exploited, several conditions will probably be brought about:

First. The west coast of the United States will probably continue to draw heavily on the fuels of British Columbia, Australia, and Japan, and to the amount imported will conserve its own supply.

Second. There will be an increasing demand for fuel oils, which, while it may not affect the production, will stimulate the search for new oil fields.

Third. The west coast will probably continue to rely on the East for its pig iron and steel, for in the absence of good cheap coke—except as Alaska can supply it or the processes of coking coals are improved—the local supplies of iron ore will not be utilized, unless, possibly, by electrical methods of smelting. As a concomitant to this, the iron ore and coking coals of the East, which are of the most value to the nation, being nearest the centers of the population, will be correspondingly diminished.

Fourth. What has been said of the relation these coals bear to the development of an iron industry on the Pacific coast is to a lesser extent true of copper smelting. Without the use of Alaska coke either the copper ores will be transported to British Columbia or Puget Sound or the coke will be brought to the copper deposits. In either case there is a loss in transportation. While it is true that these factors will affect the copper-mining industry and lead to the exploitation of only the richer deposits, yet the past few years have shown that it is economically possible to bring either the coke to the copper or the copper to the coke.

Fifth. Certain loss of fuel in transporting eastern coals to the west coast for certain purposes where their use is imperative will continue. This is, however, a small item, as the total tonnage of eastern coals to the West is insignificant.

Sixth. There will be no local supply of high-grade coals on the west coast for the use of the navy.

In considering the above facts it must be remembered that these Alaska bituminous and anthracite coal fields can be made accessible only by the expenditure of a very large amount of money. The millions of dollars necessary for the development of these fields will not be forthcoming unless provision be made by which a large tonnage of coal will be made available.

PEAT.

Peat is found in nearly every part of Alaska except in the high ranges. The humidity of the Pacific coastal zone and the consequent luxuriant vegetation favors the accumulation of peat. Southeastern Alaska is heavily forested and often has dense growth of underbrush with a flooring of moss. In southwestern Alaska timber is entirely absent, but all the lowland and much of the upland regions are covered with moss, grass, and small shrubbery. The prevailing humidity in both these districts favors the accumulation of vegetable refuse. Though there has been no prospecting for peat in this part of the Territory, deposits are known at least 15 to 20 feet in thickness and are believed to be of good quality.

Central and northern Alaska have a much smaller precipitation. Here, however, the soil is nearly everywhere mantled by a dense blanket of moss and other vegetation. This is especially striking in the extensive timberless areas or tundras which lie along Bering Sea and the Arctic Ocean. In these two provinces the subsoil is usually frozen, which retains the waters at the surface. The moss, except in excessively dry weather, is usually saturated with water. All these conditions, which promote vegetable growth and retard evaporation and oxidation, are favorable to the formation of peat. As a matter of fact, there is nearly everywhere a layer of peaty material underneath the soil. In some natural exposures peat deposits have been observed in these provinces having a depth of 30 to 40 feet. While the widespread surface layer of peat is of an inferior quality, some of the deeper-lying beds are probably of high grade. There are no data whatever at hand to estimate the available supply of peat. As, however, it is found in every part of the Territory and on the great tundras of the north, occupying at least a quarter of the Territory and comprising layers of greater or less thickness, the supply must be enormous and possibly exceeds that of the entire United States.

In the presence of more easily available fuel there has been no occasion to utilize any of the peat beds, so practically nothing is known of their fuel value, extent, or thickness, except what has been stated. Probably the only place in Alaska where this mineral fuel has been exploited is a peat bed saturated with petroleum residue, near Cold Bay, on the Alaska Peninsula, where the material has been used for fuel at the neighboring oil drills. Here, however, it is the petroleum residue rather than the peat which gives the deposit its chief value.

The peat deposits have at present no value, since lignitic and better-grade coals are too widely distributed to encourage the use of a less available fuel. The time appears also very remote when these peat deposits (except at localities where coal is absent) will be utilized. Certainly recourse to the peat will take place only when the more valuable mineral fuels are not obtainable.

PETROLEUM.

By G. C. Martin.

Petroleum may exist in the rocks at many places in Alaska, but at only four localities are the known indications sufficient to justify drilling. Wells have been drilled at three of these localities, but petroleum has been obtained in quantity at only one of them. In all of these the petroleum is of the high-grade variety, suitable for refining, like that from Pennsylvania. These four will be briefly described.

The Katalla field is situated near the mouth of Copper River, in latitude 60° north, longitude 144° west, or about 1,250 miles northwest of Seattle and 400 miles northwest of Sitka. The rocks in this field consist of Tertiary shale, sandstone, and conglomerate. The structure is complex, the rocks being steeply and intricately folded and cut by faults. These conditions would raise doubt concerning the existence of bodies of oil if it were not for the abundant seepages and the presence of oil in the wells. As it is, they increase the cost and other difficulties of drilling and make it entirely impossible to estimate the area of the probable oil-producing territory.

Sixteen wells have been drilled in the Katalla field. The result has been a moderate production of oil from one well and the demonstration of smaller quantities in three others. As only a small part of the area in which the presence of seepages suggests an oil field has been drilled, the proof of the existence of any considerable volume of oil is yet to be made.

The Cook Inlet oil fields are about 320 miles west of Controller Bay on the middle part of the west shore of Cook Inlet. Seepages are here numerous and prolific, but though several wells have been drilled, none has yet proved successful. This field is in an area of Jurassic rocks which are chiefly shales and sandstones. The folding is much more moderate than at Controller Bay, but many faults are present. The relation of the occurrence of oil to the geologic conditions has not been discovered, and hence the areas of possible oil-producing territory are entirely problematical.

At Cold Bay, on the Alaska Peninsula, 160 miles southwest of the Cook Inlet fields, there are many large seepages and several wells have been drilled, none of which has produced more than traces of oil. Here, as in the Cook Inlet field, the rocks are chiefly Jurassic shales and sandstones. The structural conditions are not unlike those on Cook Inlet.

Near Cape Yakataga, 75 miles east of Controller Bay, many large seepages are reported, but owing to the unaccessibility of the region no drilling has been attempted. These seepages are located on Miocene shale and sandstone which are steeply folded.

Summarizing, it may be said that the occurrence of oil is suggested under considerable areas in Alaska, but the presence of profitable oil pools has yet to be shown. The low price of oil on the Pacific coast and the high cost of drilling in Alaska make any attempt to develop the possible Alaska fields at present an unattractive proposition.

All considerations point to the desirability of conserving the Alaska fields until the decline of the California and Mid-Continent fields. When Alaska oil is utilized it should be for refining, and the burning of crude Alaska oil should be discouraged.

IRON ORES.

There being now practically no demand for iron ores on the west coast, such ores have not been sought for in Alaska. The only iron which has been found is that discovered incidentally in prospecting for other minerals, and thus far this has been chiefly magnetite, occurring at only a few localities along the Pacific seaboard. The following note on these deposits has been prepared by C. W. Wright:

Magnetite is the only iron ore that has been found in southeastern Alaska in commercial quantities. This ore occurs in large bodies, forming contact deposits along the contacts of diorite and limestone on Prince of Wales Island, where it is associated with the copper deposits, and occurring as magmatic segregations associated with basic intrusive rocks at several points along the mainland coast.

At the copper mines of Prince of Wales Island a considerable tonnage of magnetite carrying from one-half to 1½ per cent of copper has been developed which can not be profitably mined as a copper ore. However, if there were a market for the iron in these ores, the copper could be readily separated mechanically and the deposits mined with profit. The surface showings of magnetite in this copper district are very large, and the estimated tonnage, with a depth of only 30 feet, is about 3,000,000 tons of magnetite. There is, of course, a much greater amount of possible ore, concerning the extent of which almost nothing is known. These ores for the most part contain practically no phosphorus or detrimental impurities, and may be classed as Bessemer ore.

Explorations have been begun to develop magnetite deposits near Haines, on the mainland coast of Lynn Canal, but little is known as yet of the extent or the character of the ores.

U. S. Grant, in his study of the copper deposits of Prince William Sound, noted some hematite ores, but could not determine whether the ore was present in commercially valuable deposits. He also reports the occurrence of magnetite associated with pyrrhotite on Prince William Sound and with chalcopyrite near Seward, on the Kenai Peninsula. His investigations, on the whole, do not encourage the idea of the presence of workable iron ores in this district.

In the Iliamna Lake region there are some copper deposits which from accounts, appear to be of similar origin to those of Prince of Wales Island. With these is said to be associated a large amount of magnetite. So far as known, iron-ore bodies have been found at only one place in the interior. At this locality, which is near the head of the Nabesna River, there is a 2½-foot vein of magnetite which occurs in a limestone near the contact with an intrusive.

The conditions of occurrence of both types of southeastern Alaska magnetite deposits probably repeat themselves along other parts of the Pacific coast line, so that there is a probability that similar bodies of iron ore occur elsewhere. Though the evidence is very scant, it is not impossible that Alaska may have important iron-ore reserves.

GOLD.

INTRODUCTION.

Mr. Lindgren's general report on precious-metal resources of the United States, contained in this volume, emphasizes the fact that no definite statement of the gold reserves is possible. If this be true of the United States, it is far more so of a little-known region like Alaska, where the auriferous deposits have been found in widely distributed districts, usually separated by extensive areas, often but little prospected, sometimes almost unexplored. Moreover, except in southeastern Alaska, the auriferous deposits thus far developed are primarily those of the alluvium, and there has been little search for lodes. Therefore, in most of the gold-placer districts the possibilities of developing an auriferous lode-mining industry are almost unknown.

Geologic survey and investigation, when executed with sufficient thoroughness, lead to definite results concerning the distribution and occurrence of auriferous deposits. If a region has been mapped in detail, the geologist can outline with a fair degree of certainty those areas worth prospecting for gold. Such investigations, however, can be interpreted quantitatively only to a very limited degree in reference to placers and are practically worthless for the purpose of forecasting the gold content and reserves of undeveloped lode deposits.

The actual valuation of developed lode deposits can, of course, be carried only to the limits of the mine workings, which permit the blocking out and sampling of the ore bodies. Such an investigation can be made only at great cost and is properly the function of the mine owner and not the federal geologist.

Placer deposits, whose values are far more regular of distribution, admit of a rough valuation by the geologist; but even in the case of placers the quantitative determination of gold contents in any given body of gravel can be arrived at accurately only by extensive excavations or drilling, and by sampling. This also is evidently the function of the mine owner and not of the federal geologist. Most Alaska placer miners have done so little careful prospecting of their properties as to make their statements in regard to metal contents of but little service in estimating the placer gold reserves. Such data as are available have been carefully compiled by the Geological Survey, but while they may have value in forecasting the direction of future mining development, they are far too inexact and incomplete to admit of more than a bold guess at the gold reserves. Any estimate made at the present time can not take into account the latent possibilities of the hundreds of creeks which, though unprospected, are believed to lie within the gold-bearing area.

In the following account emphasis will be laid on the subject of general distribution and occurrence of the auriferous deposits, because it is believed that such data form the most important element in the valuation of these deposits. Given this information, together with a statement of past production, the technician at least is able to draw his own conclusions.

GEOLOGIC AND GEOGRAPHIC DISTRIBUTION.

GENERAL STATEMENT.

The known gold deposits of Alaska can be grouped into three general types: (1) Gold occurs near the contacts between granitic or other igneous intrusions and altered sediments. (2) It occurs in metamorphic schists. (3) It occurs in association with Mesozoic or Tertiary volcanics. Nearly all of the auriferous lodes which have thus far been productive are of the first type, while the second appears to be typical of most of the important placer districts. Examples of the third type have been so far limited to only a few localities. There is some evidence to indicate that the source of the gold of the placers occurring in areas of schistose rocks may be in veins which bear a genetic relation to, as well as a close association with, igneous intrusives. If this proves to be generally the case, it may be found that the deposits assigned to the first two groups may be practically identical in origin.

Most of the auriferous deposits occur in rocks which have been more or less highly altered, but the metamorphism in the placer districts has usually been more pronounced than in lode districts. There are no considerable areas of metamorphic rocks known in Alaska which are not locally more or less auriferous, so that the distribution of these rocks is one of vital importance to this discussion. The metamorphic terranes vary in age from Cambrian or pre-Cambrian to Carboniferous and possibly Triassic. There are also some altered Cretaceous beds which are locally auriferous. While in Alaska their geologic age has little direct bearing on the question of the distribution of gold, yet the most important gold fields now developed are in regions where the rocks belong chiefly to lower Paleozoic or older terranes.

Three considerable belts of metamorphic rocks traverse the Territory. One of these skirts the Pacific seaboard, embracing the auriferous lode and placer districts of southeastern Alaska (see map, Pl. XII), the Prince William Sound copper district, and some small gold-bearing areas lying in between. Its southwestward extension is found in the Kenai Peninsula and on Kodiak Island, where it includes some placer and lode deposits.

A second belt stretches southwest from the international boundary, near the famous Klondike district, and includes the Fortymile, Birch

Creek, Fairbanks, and other gold placer-bearing areas. Its extension is probably to be sought in the little-explored region lying between the lower Yukon and the Kuskokwim, and may include the newly discovered placers of the Innoko Valley.

The third belt lies north of the main Yukon Valley, includes the gold placers of the Chandalar, Koyukuk, and Kobuk districts, and may find its continuation in the auriferous metamorphic rocks of Seward Peninsula.

In addition to these broad belts thus defined, there are some smaller areas in which gold has been found, such as those of the Nizina, of the Chistochina, of the Yentna, of the Bonnifield, and of the Kantishna districts. These, with others, which will not be enumerated, have yielded some placer gold.

SOUTHERN ALASKA.

The auriferous deposits of southeastern Alaska have been investigated by C. W. and F. E. Wright and A. C. Spencer, from whose reports the following data are drawn: This province is the one in which the close association of the metalliferous lodes with the intrusives is most strongly marked, and where this relation was first worked out. It appears that the strongest mineralization lies close to the western margin of the great intrusive masses of the Coast Range. Similar intrusives are, however, widely distributed in isolated stocks throughout the coastal region of this part of the Territory and its adjacent islands, and these, too, have been found to be mineralized at a number of localities. As there are hundreds of miles of these contacts, and as but few of them have been carefully prospected, the chances of finding additional auriferous lodes appear to be good. At the same time it should be noted that the mere fact of mineralization does not imply the existence of valuable deposits, and that, in spite of the fact that this part of Alaska has been the scene of active mining for nearly thirty years, only the Juneau district has furnished any considerable gold output, and this has chiefly come from the three mines of the Treadwell group. In the Ketchikan district, embracing the southern part of southeastern Alaska, there has been some exploitation of auriferous lodes. Though some of these have carried high values, they are all comparatively small, and many have proved not very persistent.

The value of the total gold output of southeastern Alaska from 1880, when mining first began, to the close of 1907, was nearly $40,000,000, which has come chiefly from the lodes. Its future as a gold producer is promising, yet, excepting the few developed mines, there is but a small tonnage of ore in sight. With the densely forested conditions that prevail, the search for ore bodies has been much impeded, and in spite of its accessibility the region can not be said to have been carefully prospected. There is therefore little on which to base predictions of future production, except the geologic conditions which are favorable to the discovery of new ore bodies. The deepest workings (1,600 feet in the Treadwell mine) indicate a persistence of gold content in deposits of this type which is encouraging.

ST. ELIAS RANGE.

Auriferous sands whose materials have been derived from the metamorphic rocks of the St. Elias Range have been found and mined in a small way at a number of localities. These and what is known of the rocks of this range suggest that here may be a locus of future gold mining, but the facts at hand do not permit a definite statement.

KENAI PENINSULA AND KODIAK ISLAND.

Auriferous gravels have long been known to occur on the Kenai Peninsula. In fact, it was here that the Russian mining engineer Doroshin found the first placer gold (1884) known in Alaska. The placers of the northern part of the Kenai Peninsula have been productive since 1895, with an aggregate output valued at about $2,000,000. For several years, however, the production has fallen off, and it appears that the richest of the known gravels have been exhausted, though there are extensive bodies of alluvium carrying low values. The gold has been derived from metamorphic rocks, and intrusives appear to be absent. The same geologic conditions appear to prevail throughout the eastern part of the peninsula, and other discoveries may be made. Both in the Kenai Peninsula and on Kodiak Island, which lie in the same general geologic province, some auriferous lodes have been found. The accessibility of this region would permit the mining of low-grade ores, so that there is a possibility of a gold production from this district even after the placers have become exhausted.

SUSITNA BASIN AND ALASKA RANGE.

Auriferous gravels are widely distributed in the Susitna basin and have been found on both flanks of the Alaska Range. It is only within a few years that workable placers have been found, and the entire production does not exceed a few hundred thousand dollars in value. The geologic conditions in the Alaska Range are in some respects very similar to those of southeastern Alaska and are therefore favorable for the occurrence of auriferous deposits. In view of the unexplored condition of much of this field, it is useless to attempt any forecast of its future from the mining standpoint.

COPPER RIVER BASIN.

There are two widely separated auriferous areas in the Copper River basin. The northern area lies on the south flank of the Alaska Range, and the southern area is a western extension of the St. Elias Mountains. What has been said of the future of mining in these ranges applies to these districts excepting that there has been some gold output from these, and they will undoubtedly continue to produce, as systematic mining has hardly commenced.

ALASKA PENINSULA AND ADJACENT ISLANDS.

The Alaska Peninsula region furnishes the only developed example of the third type of auriferous deposits, namely, an occurrence in volcanic rocks. This is at the Apollo mine, which has made a considerable production. Recent information leads to the opinion that there are other similar types of deposit in this general region. If such prove to be the case, this district may also swell the gold production, though at present its entire annual output is confined to a few thousand dollars taken from beach placers and a small production from lode deposits.

YUKON BASIN.

Mining was begun in the Alaska Yukon about 1887, when the Fortymile placers were discovered, but the total production up to the time of the discovery of the Fairbanks placers in 1901 was less than $6,000,000 in value, whereas the production for 1901 to 1907, inclusive, is valued at nearly $30,000,000.

The best known and probably most valuable of the placers of the Yukon basin lie in the so-called "Yukon-Tanana region," embracing an area of some 40,000 square miles between the two rivers, of which about half falls in what may be designated the "auriferous zone." Within this province lie the Fortymile, Birch Creek, Fairbanks, Rampart, and Hot Springs districts, as well as some smaller ones, all of which have produced placer gold.

This province is the best example of gold occurring in metamorphic schists, but some of its auriferous deposits appear to be intimately associated with intrusive rocks. So far as known, the geologic conditions which prevail in the developed placer districts persist over much of this field. Certain it is that auriferous mineralization is widely distributed, for fine particles of gold occur nearly everywhere in the alluvium. Much of the Yukon-Tanana region is so inaccessible as not to attract the large operator. While the bonanza hunter has hurriedly traversed most of this region, the scarcity of bed-rock exposures and other conditions adverse to prospecting prevent such hasty investigations from yielding definite results as to the presence of gold deposits. Even in the best-known and most accessible parts of the region new discoveries of placers are constantly being made. All these facts indicate that this may be one of the largest placer-gold reserves of the Territory.

The data bearing on the gold contents of the gravels known to carry values have been carefully assembled by L. M. Prindle and F. J. Katz, and these indicate a reserve of about $100,000,000 in value for the ground which has been more or less prospected. This is certainly a conservative estimate, for it takes into account only the auriferous gravels which can probably be mined under the present conditions, or those that will prevail during the next few years, and does not make any allowance for the large unprospected areas.

A belt of schists lying north of the Yukon, extending from Chandalar Valley into the Koyukuk Valley, has been found to be auriferous. Mining has been going on in the latter district since 1899, with a production of probably over a million dollars in value. This field is one of very high cost in mining, and there are probably more extensive deposits with a smaller gold tenor than those now exploited. The Chandalar district has made but a small production, mining having been begun in 1906.

Placer gold has been found at several places in the lower Yukon basin, notably on the Melozitna, on Ruby Creek, and on the Innoko. Too little is known of the character or extent of these deposits to permit any statement as to their future importance. They prove, however, a wide distribution of the auriferous deposits and indicate possibilities in the way of future discoveries.

Nowhere in the Yukon basin has there been any lode mining, and systematic prospecting for auriferous veins has hardly been inaugurated. As a rule, the mineralization in the schists appears to be disseminated rather than concentrated, but there are exceptions to this rule. Some lode deposits have been found which, in a more accessible region, could probably be profitably exploited. The subject of the future of lode mining in this field does not admit of solution from the data in hand.

SEWARD PENINSULA.

Placer mining was begun on Seward Peninsula in 1897, but it was not until 1899 that the annual gold production exceeded $100,000 in value. The total output of gold up to the close of 1907 was over $44,000,000 in value. Practically all of this gold was taken from the placers, for only one small lode mine has made any considerable production, though a few tons of ore have been taken from several others.

The auriferous deposits of the peninsula can be roughly outlined as occurring in two general belts. One, about 40 miles wide, stretches a little north of east and skirts the southern shore line of the peninsula, embracing the gold placers of Nome, Solomon, and Council. This belt has been traced about 120 miles. The second belt stretches from the neighborhood of Port Clarence to Kotzebue Sound, a distance of about 140 miles, with a width of about 40 miles. In this belt are included the auriferous gravels of Teller, Kougarok, Inmachuk, and Kiwalik. As outlined, these belts embrace an area of about 10,000 square miles. In addition to these areas, evidence of mineralization has been found in the extreme western part of the peninsula, which includes the cassiterite, galena, and other ores of the York region.

In describing the geographic distribution of the mineral deposits of the peninsula, it is not intended to imply that there is any great regularity in their occurrence. As a matter of fact, the distribution of the valuable minerals within these zones is very irregular. The placer gold seems to have been derived, for the most part, from contact zones between massive limestones and various types of schists. P. S. Smith's recent investigations show that other forms of auriferous deposits are those found in black siliceous slates and those in chloritic schists. Other types of mineral occurrence are those of cassiterite, galena, and other ores which are found in association with granitic intrusives near the western end of the peninsula and which have recently been described by Adolph Knopf.

While the types of mineral occurrence might be multiplied, for they include copper, antimony, tungsten, and other ores, what has been stated is sufficient to show that there is great variety in the form of mineralization. It also indicates that, in spite of the fact that there is now but little lode mining there is sufficient ground to believe that such an industry may be developed as to make it necessary to take it into account in estimating the gold reserves.

Though the Seward Peninsula auriferous gravels have been far more prospected than those of the Yukon-Tanana region, yet quantitative data of their gold contents are exceedingly scant. These data, however, were carefully compiled some years ago, and deductions made from them regarding the placer-gold reserves.[a] Estimates were made by two different methods. By one the gold contents of auriferous gravels was valued at $265,000,000; by the other, $325,000,000. It can not be too often repeated that such computations are no more than mere approximations, for they are based on certain assumptions as to the gold tenor of the gravels, etc., which do not now admit of proof. These reserves appear to be two or three times as large as those estimated for the Yukon-Tanana region. This is due to the fact that in Seward Peninsula the data seemed to justify an attempt at an estimate of gold tenor for the entire body of auriferous gravels, while in the Yukon-Tanana region the information at hand only warranted an estimate of the auriferous gravels of the productive areas.

STATISTICS.

The systematic collection of statistics of gold production for Alaska was begun only in 1905, and the distribution of the output previous to that year is only an approximation. In the preparation of the following table the best available data have been used. In this table of production the Pacific coastal belt includes southeastern Alaska, the St. Elias region, and the Alaska Peninsula and adjacent islands, while under Copper River and Cook Inlet region are embraced the Kenai Peninsula and the Copper River and Susitna basins. The

[a] Gold placers of Seward Peninsula: Bull. U. S. Geol. Survey No. 328, 1908, pp. 135–139.

other geographical terms used in this table, Yukon basin and Seward Peninsula, need no definition.

Value of gold production of Alaska, with approximate distribution, 1880–1907.

Year.	Pacific coastal belt.	Copper River and Cook Inlet region.	Yukon basin.	Seward Peninsula.	Total.
1880	$20,000				$20,000
1881	40,000				40,000
1882	150,000				150,000
1883	300,000		$1,000		301,000
1884	200,000		1,000		201,000
1885	275,000		25,000		300,000
1886	416,000		30,000		446,000
1887	645,000		30,000		675,000
1888	815,000		35,000		850,000
1889	860,000		40,000		900,000
1890	712,000		50,000		762,000
1891	800,000		100,000		900,000
1892	970,000		110,000		1,080,000
1893	833,000		200,000		1,038,000
1894	882,000		400,000		1,282,000
1895	1,569,500	$50,000	709,000		2,328,500
1896	1,941,000	120,000	800,000		2,861,000
1897	1,799,500	175,000	450,000	$15,000	2,439,500
1898	1,892,000	150,000	400,000	75,000	2,517,000
1899	2,152,000	150,000	500,000	2,800,000	5,602,000
1900	2,606,000	160,000	650,000	4,750,000	8,166,000
1901	2,072,000	180,000	550,000	4,130,700	6,932,700
1902	2,546,600	375,000	800,000	4,561,800	8,283,400
1903	2,843,000	375,000	1,000,000	4,465,600	8,683,600
1904	3,195,800	500,000	1,300,000	4,164,600	9,160,000
1905	3,430,000	500,000	6,900,000	4,800,000	15,630,000
1906	3,454,794	332,000	10,750,000	7,500,000	22,036,794
1907	2,891,743	275,000	9,183,000	7,000,000	19,349,743
Total	40,311,937	3,342,000	34,964,000	44,262,700	122,935,237

Of the total about $37,000,000 must be credited to lode production, which is nearly all included in the Pacific coastal belt of the above table. Up to the close of 1907 there was only one productive auriferous lode mine in Seward Peninsula, and none either in the Yukon basin or in the Copper River and Cook Inlet region. The auriferous lode production, with the exception of that of the Apollo mine on Unga Island, southwestern Alaska, and a few small mines of the same general region, together with a small gold output from the copper deposits of Prince William Sound and from the auriferous lodes of Seward Peninsula, is all from southeastern Alaska. As the Treadwell group of mines has an output valued at $30,402,236, it will be seen that nearly five-sixths of the auriferous lode production is from this one ore body.

Accurate data regarding the source of the gold have been available only since 1906. They are summarized in the following table:

Source of gold in Alaska, 1906–1907, in values.

Kind of ore.	1906.	1907.
Placers	$18,607,000	$16,491,000
Siliceous ores	3,348,943	2,764,885
Copper ores	80,851	93,858

This table indicates that the placer production now overwhelmingly dominates in the total of gold output. This has, however, only been true since 1897, for previous to that time only about a third of the annual gold production was from the placers.

SUMMARY AND CONCLUSION.

It has been shown that gold is very widely distributed in Alaska, both in lodes and in placers; also that the production of the lode mines, outside of the Treadwell group, is insignificant. This does not mean, however, that the outlook for auriferous lode mining is not hopeful, for this is far from being the case. Up to the present time the cost of mining, except along a part of the Pacific seaboard, has been practically prohibitive for a lode-mining industry which is not based purely on the exploitation of bonanzas. Even along the seaboard there has been little systematic search for lodes. Most of the gold ores which have been found in the inland region have been of so low a grade as not to encourage their exploitation under present conditions of transportation. It will be clear, therefore, that there is no basis whatever for a quantitative statement of the gold reserves in the lodes of the Territory.

The known wide distribution of placer gold augurs well for future discoveries of this type of deposit. Most of the districts where mining operations are now going on have been so little prospected that little is known of their gold reserves. Some estimates, however, have been made for placer-gold reserves of the Yukon-Tanana region and Seward Peninsula. Those of the first province were made to include only the producing areas, while in Seward Pensinsula the bulk and value of the entire body of auriferous gravels was estimated. In the Yukon-Tanana region, which includes much the largest auriferous area, the gold contents of the producing part of the field are approximately valued at $100,000,000, not including the very large unprospected areas, while the auriferous gravels of the entire Seward Peninsula are estimated to contain about $300,000,000. It can not be too strongly emphasized that though all the data have been carefully compiled and the computations made with great care, yet there are so many unknown factors that the results are little more than guesses. No quantitative data of any kind are available for the other smaller districts, ten in number, but it is probably safe to estimate the gold in them as between $50,000,000 and $100,000,000. These values total about $500,000,000, which is the nearest approximation that can be given of the gold-placer reserves of the Territory. It is not impossible, however, that the Yukon-Tanana region alone may carry this amount of gold.

SILVER, LEAD, AND ZINC.

The silver production of Alaska has practically all been won incidentally to gold mining, and much the larger part of it has been recovered from the placer gold. There has also been a small recovery from the copper ores.

The total production of silver from 1880 to 1907, as nearly as can be determined, was 1,677,159 ounces, of which over three-quarters was from the placer gold. The following table shows the source of silver for the period that statistics have been available:

Source of silver from Alaska, 1906–7.

Kind of ore.	1906.	1907.
	Ounces.	*Ounces.*
Placers	76,835	49,847
Siliceous ores	15,772	14,653
Copper ores	18,577	34,357

There has been no lead production from Alaska, except a few tons recovered in the reduction of other ores. Galena is widely distributed, and some promising ore bodies have been prospected, but nothing is known of their extent. Such galena deposits occur in southeastern Alaska, on Prince William Sound, and in Seward Peninsula. Though attempts to exploit a galena ore body on Seward Peninsula date back to 1881 and have been continued intermittently to the present time and some small shipments have been made, this mine, called the Omalik, has never been on a commercial basis. The same statement applies to the mining of galena ores in other parts of the Territory.

Zinc blende has been found at a number of localities in Alaska, but the value of the ore bodies remains to be proved. No attempt has been made to mine zinc ores.

There are no data at hand on which to base any estimates of the reserves of the three metals here under consideration. With the increase of the gold output there will be a corresponding increase in the silver production.

COPPER.

DISTRIBUTION AND OCCURRENCE.

Copper ores are known to occur in commercial quantities on Prince of Wales Island (southeastern Alaska), Prince William Sound, and in the Chitina Valley of the Copper River district. They have also been found in a belt running from the Nabesna to the upper White River, in the Lake Iliamna region, and on the Seward and Kenai peninsulas. In these no ore bodies of proved commercial importance have been opened up, but the outlook for such in some localities appears hopeful.

On Prince of Wales Island, according to C. W. Wright, the copper ores, which are sulphides, occur along the contact of intrusives and limestones. U. S. Grant's description of the copper ores of Prince William Sound shows these to be sulphide ores which occur as lenses along shear zones. These shear zones are in greenstones or in contact zones between greenstones and graywackes. The Chitina belt, according to F. H. Moffit, includes both native and sulphide copper deposits. These occur at or close to a contact between a heavy greenstone (altered lava) and a limestone. This contact, along which mineralization seems fairly persistent though ore bodies of proved value have been exposed at only a few localities, has been traced for upward of a hundred miles.

The Nabesna-White River copper belt is of a similar character to that of the Chitina Valley, though here the value of the ore bodies found remains to be proved by further development work. In the Iliamna Lake region copper ores are said to be similar in occurrence to those of southeastern Alaska. Little is known of the other copper-bearing localities of the Territory.

STATISTICS.

Copper mining was first attempted on Prince of Wales Island in 1880, but the project was soon abandoned. The industry was begun again in 1900 in Prince William Sound, and five years later the Prince of Wales Island deposits also began producing. The total output of copper from Alaska up to the close of 1907 was 20,843,352 pounds, of which 12,368,975 pounds came from the Prince of Wales Island mines and the balance from Prince William Sound.

SUMMARY.

It is impossible to make any estimate of the tonnage of copper-ore reserves of the Territory. The developed ore bodies have been computed in a few mines by the operators, but even if these figures were available they would have little bearing on the problem of the ultimate reserves. Less than a score of copper mines have been opened up in Alaska, and all but one of these are located in two districts. In one promising district there has been only a little surface prospecting and this also holds true of the several widely distributed copper deposits which are not included in the four best-known districts. Even in the largest mines the workings in few cases extend to a depth of more than one or two hundred feet. It is evident, therefore, that the ore blocked out in the mines, whose copper content is probably less than 200,000,000 pounds of metal, has little bearing on the question of ultimate reserves, for it would not take into account either the undeveloped ore bodies already found or the possibilities of discoveries in the little-prospected fields. Moreover, any estimate of tonnage could include only the ores which can be mined at the present price of copper, while an increase of this price would make available lower-grade ores which can not now be commercially exploited. The problem is furthermore complicated by the irregularity of many of the copper deposits.

There can be no doubt that the output of copper from the Territory will increase during the next few years. The accessibility and cheapness of exploitation of the ores of the Pacific coast province invite copper-mining enterprises, in spite of the irregularity of occurrence of most of these deposits. A railway is now under construction up the Copper River valley which will not only lead to early shipments of a large amount of copper ores from the deposits already found, but will also stimulate further search and probably lead to the discovery of other ore bodies.

WATER RESOURCES.

INTRODUCTION.

The principal value of the water resources of Alaska is for generating power to be used for mining, now the only extensive industry. There are two general methods of utilizing the water power: (1) By converting it into electricity or other form of energy, for the purposes of lode and placer mining. By such means the power can be transmitted to the locality of use. This form of utilization is now almost entirely confined to the Pacific coastal belt of the Territory. (2) The more direct use of the water under head for sluicing, elevating, and hydraulicking the auriferous alluvium. This second form of utilization has been extensively practiced in small plants throughout the placer districts.

Many of the gold placers and lode deposits can be profitably exploited only by the utilization of water power. The water powers are also valuable to other industries, but up to the present time have not been so utilized, except in a small way for running electric-light plants, machine shops in some of the coastal towns, and some fish-product manufactories.

An adequate knowledge of the distribution, volume, and gradients of the surface water is, therefore, of first importance to the industry of the Territory. The underground waters of Alaska need not here be considered; none such have been developed and little is known about their occurrence. There is a possibility that in some of the placer districts there may be underground waters in sufficient quantity to justify their development for purposes of supplementing the inadequate surface waters. Artesian waters have in a few instances been found underneath the layer of perpetually frozen ground. These appear to be exceptional conditions, as usually the frost extends all the way to bed rock. Such ground waters, where they have been found, are probably very local in extent. There are also some potable waters derived from springs, but these, as well as the surface water used for towns, need not here be considered.

Facts regarding the water supply are scant and based almost entirely on the results of the investigations of the United States Geological Survey. These results are of two kinds—(1) the records of stream gaging, which furnish information as to the volumes of the watercourses, and (2) the topographic maps, which show the distribution of the water, as well as the gradients of the streams in which it flows. Measurements of stream flow have been carried on for three seasons (1906–1908) in some of the important placer districts of Seward Peninsula, for two seasons (1907–1908) in the Fairbanks district, and for one season (1908) in the Hot Springs, Rampart, and Birch Creek districts. These measurements furnish the only data on stream volume throughout the Territory, though a few corporations have obtained records from small areas preparatory to the installation of hydraulic plants.

The topographic data are more complete, for reconnaissance maps (scale 1:250,000, with 200-foot contours) of some 121,252 square miles have been made, which cover most of the important mining districts and about 20 per cent of the entire area of Alaska. These reconnaissance maps furnish a general conception of drainage basins and stream gradients. In addition, 2,732 square miles have been mapped in detail (scale 1:62,500, with 25, 50, or 100 foot contours), yielding accurate information of the extent of drainage basins and of stream gradients.

Only two of the larger geographic provinces of Alaska will here be considered, namely, (1) the Pacific coastal region and (2) the central region, for, as far as can now be foreseen, it is only in these two that the water has any industrial value. These two provinces differ essentially in climate and relief and, indeed, present almost the extreme conditions as regards the occurrence and utilization of surface waters. In the coastal belt as a whole the topography is extremely rugged and many of the streams are fed by perennial snows, which, together with the large precipitation (75 to 120 inches), yield a large run-off with no great fluctuations during the summer months.

Beyond the coastal barrier the climate is semiarid (precipitation 10 to 20 inches), the relief is weak, and hence stream gradients are low, while there is no permanent snow. Another feature of the precipitation is that summer rainfall is very local. Moreover, the general frozen condition of the subsoil to bed rock probably prevents any considerable ground storage. These conditions make for a small run-off per square mile and very marked fluctuations in stream volumes. Moreover, the low relief makes it difficult to utilize the water under head.

Seward Peninsula, though not strictly a part of the central region, possesses the same general hydrographic conditions. The precipitation (10 to 30 inches), however, averages a little greater than in the Yukon basin. Here also the low stream gradients make much of the run-off unavailable for placer mining.

The conditions affecting surface waters in the area drained by Susitna and Copper rivers differ somewhat from those existing in the Pacific coastal region and in the inland province. In part this area has as strong relief as that along the seaboard, yet its precipitation is far less. On the whole, however, this region is better supplied with water than the Yukon basin.

PACIFIC COAST REGION.

In southeastern Alaska alone has there been any considerable utilization of water power. The Census Bureau collected the statistics of the developed water power in this part of the territory. Through the courtesy of the Director of the Census the following data are available. The statistics show that a total maximum of 15,699 horsepower has been developed and that 100 water wheels have been installed. Of this maximum 2,816 horsepower is available during low-water season. It is reported that at the localities where this power has been developed there is 14,135 horsepower available. Of the developed horsepower 3,403 horsepower is utilized by electric-light plants, canneries, and some other small industrial enterprises, and the rest by mining and smelting plants. The Treadwell group of mines alone utilizes some 6,647 horsepower. In addition to the above a few hundred horsepower is developed in other parts of the Pacific coast belt.

Southeastern Alaska affords conditions which are peculiarly favorable for the development of water power. The glaciation of this region has developed a topography which, with its cirques and many lakes lying at considerable altitude above sea level, is favorable to water storage. While the run-off during the summer months is much larger than during the winter, yet there are many localities where a large amount of power can be developed, even during the low-water stages.

YUKON BASIN.

There are no records which make it possible to state the quantity of water used for placer mining in the various Yukon districts, but it is known to be a large amount. Nor has stream gaging progressed far enough to determine the available water. However, it is probably safe to say that within a few years every supply so situated as to be directly applicable to placer mining will be utilized. Even when this has been brought about, the supply will be inadequate for the gold placers already opened up. In addition to this water directly applicable to placer mining, there are a number of water powers which can be utilized for certain mining operations by transformation to other forms of energy. It is probable that even after the development of these water powers the demands of future mining interests will not have been met. The utilization of coal to supply this demand is discussed elsewhere in this report. Mention should be made in this connection of the possibility of developing power along the streams which find their source in the high mountains stretching along the southern margin of the Yukon basin. These streams have not been measured and but few have been surveyed. They are known, however, to have a much larger volume than those of the central region proper, and the topography would appear to be favorable to water-power development. Some of the important placer districts lie within 50 or 100 miles of the mountain front.

The following table, which is based on the investigation of Mr. Covert, presents in summary form the available data regarding the run-off in the districts which have been investigated. It can not be too strongly emphasized that, as this is based on only one or two seasons' observations, the data presented are only an approximation.

Estimates of mean annual discharge and run-off of drainage basins in Yukon-Tanana region, Alaska.

[By C. C. Covert.]

District.	Year.	Second-foot per square mile.	Depth in inches.	Per cent estimated.[a]	Duration of record.	
					From—	To—
Fairbanks, 826 square miles	1907	0.780	10.60	62	June 20	Oct. 15
	1908	.710	9.66	54	May 1	Oct. 21
Mean		.745	10.13	58		
Hot Springs, 56 square miles	1908	.44	6.00	95	June 6	Sept. 26
Rampart, 212 square miles	1908	.54	7.40	90	...do....	Do.
Circle, 2,150 square miles	1908	.99	13.50	91	June 26	Oct. 13

[a] The run-off for the period not covered by records was estimated at approximately 0.25 second-foot per square mile.

SEWARD PENINSULA.

What has been said of the Yukon basin applies also to Seward Peninsula. Here, too, nearly all the water available for direct application to placer mining will soon be utilized, and even then can not meet the demand. Some important undeveloped water powers are known to exist in this province.

The topography of Seward Peninsula, like that of the Yukon basin, is of low relief, and therefore a comparatively small part of the run-off can be made available for mining. In the mountain mass, including the Bendeleben and Kigluaik ranges, the conditions for water storage are somewhat more favorable than in other parts of the peninsula. Here there are some glacial cirques, and though these are of comparatively small extent, they have an influence in the conservation of water and snow. What is of still greater importance, however, is the greater rainfall which occurs in these high mountains compared with other parts of the peninsula.

Mr. Henshaw has summarized his three seasons' observations on stream flow in Seward Peninsula in the table which follows. The value of the data contained in this table will be increased by considering the character of the topography of the basins whose run-off is given. Kruzgamepa River, at Salmon Lake, drains a basin typical of the Kigluaik and Bendeleben mountain areas. Kuzitrin River and Imuruk Lake lie in the northern portion of the peninsula and represent the area north of the mountains. There are not sufficient data to make any estimate of the yearly run-off from the country south of the mountains.

Estimates of mean annual discharge and run-off of drainage basins in Seward Peninsula, Alaska.

[By F. F. Henshaw.]

Stream.	Year.	Second-feet per square mile.	Depth in inches.	Per cent estimated.	Duration of record.	
					From—	To—
Kruzgamepa at Salmon Lake, 81 square miles	1906	3.68	50.2	38	May 28, 1906	Sept. 30, 1906
	1907	3.77	51.1	40	June 15, 1907	Oct. 5, 1907
	1908	2.40	32.6	63	June 21, 1908	Sept. 30, 1908
Mean		3.28	44.6	47		
Kuzitrin at Lanes Landing, 1,720 square miles	1907	.46	6.2	100		
	1908	.39	5.3	40	June 1, 1908	Sept. 30, 1908
Mean		.42	5.7			
Imuruk Lake, 99 square miles	1906–1907	.59	7.9		Aug. 16, 1906	Aug. —, 1907
	1907–1908	.50	6.8		Oct. —, 1907	Sept. 25, 1908
Mean		.54	7.4			

The discharge of Kruzgamepa River at Salmon Lake has been assumed to decrease regularly from October 1 to a minimum of 30 second-feet on April 20, then to increase slowly until the break-up of the ice, and more rapidly until the date of the beginning of records, which has been taken as the maximum for the year. The run-off from snow for 1908 was taken as 70 per cent of the mean of that for the two previous years.

The run-off of Kuzitrin River for May, 1908, was taken as 75 per cent of that for June, and for the remainder of the year as 0.06 second-feet per square mile. The run-off for 1907 was estimated by comparison with the two years' record at Imuruk Lake. The flow into Imuruk Lake was determined by closing the dam at the outlet and noting the rise of the water surface.

INDEX.

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