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Iron

A Materials Survey

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8574

Iron

A Materials Survey

By Horace T. Reno and Francis E. Brantley
Division of Ferrous Metals, Washington, D.C.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
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IRON: A MATERIALS SURVEY

by

Horace T. Reno[1] and Francis E. Brantley[1]

ABSTRACT

This information circular surveys the iron ore industry of the world. It presents a comprehensive statistical record through 1970 of the U.S. iron ore industry and world trade patterns. The supply position of the United States and the other principal industrial countries of the world are summarized; detailed information is given on iron ore production, consumption, imports, exports, mine capacities, substitutes, properties, and uses. There is a generalized discussion of the technology of mining and smelting iron ore, with a selected bibliography on the current state of these arts. The circular contains a summary economic account of world iron ore resources, and discussions of the structure of the domestic and principal foreign mining industries, iron ore mine employment and labor productivity, research and development, legislation, government programs, and strategic factors.

INTRODUCTION

This survey, one of a series of Bureau of Mines publications designed to serve the needs of Government and industry for a comprehensive source of information on industrial and strategic minerals and metals, discusses iron and the iron industry in the United States and throughout the world.

The metal iron has been used chiefly for its properties of strength and malleableness; the widespread occurrence and availability of its ore have allowed for the common usage of iron. The Iron Age started in Europe and Asia about B.C. 1000, and by the time of the Middle Ages ironmaking was practiced in all parts of the world except North America. The first integrated steel plant in the United States, Hammersmith, in Massachusetts, was completed about 1660, and iron ore was discovered in the Lake Superior district in 1845 and on the Mesabi Range in 1890. The depletion of the high-grade ore deposits of the Lake Superior District was in sight after the high-production years of World War II. The United States began importing substantial quantities of iron ore in 1954, and the first taconite plants were operating in 1956. The years since then have marked revolutionary changes in the iron ore industry in prospecting, exploration, development, mining, beneficiation, and smelting. Judging by current research activity, change in the industry will be as dynamic in the 1970's as it has been in the preceding two decades.

Iron ores are mixtures of iron-bearing minerals with varying quantities of

[1] Physical scientist.

mineral impurities which occur naturally. They are grouped together because of their iron content; however, they can have several forms with different chemical and physical characteristics. The ore retains its identity through various upgrading processes to its ultimate use. In the natural state, iron ore is known by its principal mineral constituent, but low-grade ores are often identified by the type of rock in which they occur. Thus, we have hematite, magnetite, and limonite ores which can be micaceous, calcareous, manganiferous, or titaniferous; other ores may be further identified for example, as taconite, jaspilite, or itabirite.

Iron ores reach markets in natural forms as concentrates, or as agglomerates. Grades are determined by iron content, types and amounts of impurities, and physical properties. The ore is used mainly for the iron it contains and to a lesser extent for its physical and chemical properties.

Iron ore is widely distributed geographically. It is mined economically on every continent. Reserves similar in grade and characteristics to those presently being mined total more than 130 billion tons. At the present rate of consumption, these reserves should meet world demand for several hundred years, assuming that economic and physical environments remain basically the same.

Conventional prospecting methods, based on a knowledge of geology and geophysical methods, are used to find and explore iron ore deposits. By far the largest part of the iron ore produced is mined in open pit mines with large-size conventional excavating equipment. Essentially all ore mined in a modern industrial environment is crushed, screened, and sized, and the concentrated using gravity or magnetic methods. Most concentrates are agglomerated to form pellet or sinter, which is smelted in a blast furnace using coke for heat and reductant. However, in unique economic and physical environments, iron ore may be processed to sponge iron, which is used as is, or made into steel in an electric furnace.

The iron mining industry of the world has grown spectacularly. About 300 million tons of ore per year was produced in the early 1950's; in 1970, production totaled 755 million long tons.[2] The industry is widely scattered but there are notable concentrations in the iron formation of the Lake Superior District and the Labrador Trough of North America, the Minas Gerais District of Brazil, the minette ores of Great Britain and Western Europe, the magnetite deposits of the Scandinavian peninsula and the Soviet Union, the Iron-bearing mountains of Western Africa, the hematite deposits of India, and in newly developing hematite ore fields of Western Australia. Independent companies produce less than 15 percent of the iron ore in the United States; the remainder is produced by steel companies or by associations of two or more concerns that have been formed solely to mine on a scale larger than any one company can support. The pattern of the world industry is similar to that of the United States, a large part of it being controlled or influenced by steel producers. The iron mines in Communist countries are owned by the state. There is a tendency in Communist policy matters to lump the iron under heavy industry, the priorities for which are invariably dominated by the sector responsible for producing iron and steel.

The iron ore industry of the United States employs 25 to 30 thousand people, who, as a group, are skilled above the average of workers in manufacturing, construction, and service industries. The output of iron ore per man-shift has increased more than tenfold since the turn of the century. However, output of iron-in-ore per man-shift has increased only four and a half times.

Research has proved to be the lifeblood of the domestic iron-mining industry. Integrated steel companies direct their research principally toward development; basic studies are of only incidental importance. Federal and State agencies conduct principally basic research, with development projects being undertaken only in unusual circumstances. Private industries and government agencies often cooperate to investigate specific problems of mutual interest that cannot be handled individually.

[2] The quantities used throughout this publication are long tons unless otherwise specified.

Iron ore is vital to the economy of the United States during peace or war, but to stockpile it as a strategic material has been deemed impractical. On the basis of known reserves, present technology, and current economies, the United States is about two-thirds self-sufficient in iron ore.

Each chapter in this report contains a bibliography keyed to the information presented. Italicized numbers in parentheses found throughout refer the reader to specific items in these bibliographies.

CHAPTER 1.—HISTORY

Coloring in the drawings and pottery of the prehistoric peoples of Asia and the Near East provides unmistakable evidence that iron ore was used and valued even then. Archeologists have found that the earliest inhabitants of both North and South America used red iron oxide. When Columbus came to America the Indians were using the red and brown ores and yellow ochers for cosmetics and war paint. However, the earliest proven use of metallic iron was about the year 2000 B.C.

The first metallic iron known was meteoric. The Egyptians called it ba-en-pet, or metal from heaven. At that time it was more valuable than gold or copper, as witnessed by the ancient knives that were made with bronze handles, because iron was too expensive to use for the whole knife.

Iron smelting probably was discovered by accident in Asia sometime before 2000 B.C. But about then, the Assyrians brought iron smelting to the Near East from the Hittites, who had imported it from Asia Minor.

Pharoah's chariots, which he used in pursuit of the Israelites, were partly built of iron. Goliath's spear had an iron head. His battle with David marked the approximate beginning of the Iron Age.

By 400 B.C. iron was in common use among the Romans, who ascribed its origin to Vulcan, the subterranean God of Fire. The Celts reportedly used iron swords at the Battle of Anio in that same year. This is plausible because when the Romans invaded Britain in 55 B.C., the Celts who preceded them had already introduced iron and ironmaking. The Germanic tribes on the Continent obtained their metallurgical know-how from the Celts. As a matter of fact, most of the nations of ancient Gaul had iron metal ornaments, and by 400 B.C. they had good knowledge of ironmaking.

In A.D. 320 the Indians demonstrated their skill in ironmaking by casting a 40-foot-high pillar at Delhi to celebrate the Bengal campaigns of Chandragupta. The iron was so pure that the pillar has changed little in the 16 centuries since. It stands in Delhi today, looking much the same as when it was cast.

Until the Middle Ages only the richest iron ore, 70 percent iron or better, could be used. The ore was heated with charcoal, which also reduced the oxides. Researchers have estimated that it took 14 tons of charcoal to get a ton of ore hot enough to work, and that the iron recovery was about 15 percent. The product was soft, malleable, wrought iron, except when (at first by accident) it absorbed enough carbon to make steel. In the Middle Ages ironmaking was practiced in all parts of the world except North America. The smelting process was primitive, but the iron produced was excellent.

The Turks operated iron forges for making the implements of war while slaves of the Khan of Geougan in Asia in the sixth century. With this knowledge they forged weapons that became the instruments with which they gained their own freedom. A primitive blast furnace was reported in Central Africa at Kamalia in what is now Uganda. The Cythians of Siberia were among the first to have iron and worshipped a sword of iron as the Shrine of Mars. Peruvians were smelting iron ore when the Spaniards arrived. North American Indians, however, first learned of iron the hard way, from Spanish swords.

The Germans were the leading iron metallurgists of the time and took the art to Scandinavia in the 13th century. The Western European iron industry developed contemporaneously with that of Germany. Regular iron ore smelting did not reach Russia until late in the 15th century. To the south, the Moors had a talent for steelmaking and produced some of the world's best steel at Toledo on the Iberian Peninsula.

By the first of the 15th century, the ironmaking process had advanced so that lower grade ores could be smelted. Wrought iron was produced from the low-grade ore by crushing it, mixing it with limestone, and then with marl to hold the two together. The mixture was surrounded with charcoal and heated to a pasty mass in a forge similar to the type found in most blacksmith shops. The impurities were removed by repeated hammering of the heat-softened mass, reheating it when necessary. It was not a very complex process considering that it took 34 centuries to develop.

The blast furnace process to make pig and cast

iron also was a product of evolution, but it came a good deal faster. The furnaces, called schaft or stuckofen furnaces, originated in Europe, but the know-how soon reached England. In the time of Edward III (1327-1377) almost all iron was wrought in forges. But in the time of Henry VIII (1509-1547), less than 2 centuries later, by far the greater part was cast into pigs and then refined. During that time Lord Seymour of Sudeley was casting blast furnace metal into guns and shot at Worth and Sheffield. The English cannon was the principal product of the iron industry and its exportation was subject to State supervision and control. Use of coal as a substitute for charcoal in a blast furnace was patented by Lord Dudley in 1621, but for one reason or another the process was not applied profitably until well into the 18th century.

The blast furnace gave great impetus to the development of the iron and steel industry. Through the 16th and 17th centuries the industry advanced rapidly. All the iron ore was mined in open pits. Since charcoal furnished heat for smelting, iron works by necessity were built in close proximity to forests and moved to new fields when the wood supply ran out. Spain was the only country that replanted, and consequently the industry declined in England and in parts of Europe early in the 18th century. It was saved by the general substitution of coke for charcoal in the 1760's.

America with its great primeval forests offered almost unlimited opportunity to develop a charcoal-based iron smelting industry. The early settlers attempted to take advantage of it. Lacking the know-how themselves, they brought skilled ironworkers from England and Wales. Iron ore was discovered in Virginia in 1608 and in the other Colonies soon thereafter, but it took almost 50 years to get a sustained smelting operation going.

Sir Walter Raleigh sponsored the first attempt at ironmaking in the New World at Falling Creek, Va. The enterprise was started about 1610. Tools of the trade and workmen were brought from the famed Warwick, Staffordshire, and Sussex ironworks. Many of the workmen died in the new environment, and although some £4,000 was spent on the project in the next 11 years, there is doubt whether any iron was produced. The project was abandoned after an Indian massacre on March 22, 1622, in which the working crew was killed, the ironworks were ruined, and all the ironworking tools were thrown into the river.

Historians say it is practically certain that the first successful iron smelting operation in North America was started at Braintree, Mass., in 1644. The project was sponsored by a group of English investors, represented by John Winthrop, Governor of Massachusetts. His son, John Winthrop the Younger, directed all operations. The site of the blast furnace at Braintree is today within the limits of Hall Cemetery in West Quincy. The blast furnace at Braintree was in production by 1645 but was abandoned in 1646 for lack of ore.

Winthrop and his group also built the Hammersmith works at Saugus on the Saugus River. Hammersmith was the first sustained integrated plant in America. The site was acquired in 1644, construction of the works started in 1646, and full production was achieved in 1650. The works have been restored on the original site by the American Iron and Steel Institute and are today open to the public as a tourist attraction.

Hammersmith was built by men well versed in the art of smelting iron ore. It was planned to smelt bog iron with charcoal using sea shells and the native gabbro for flux. The site was chosen only after careful investigation of the water, power, fuel, and ore supply. The iron deposits were systematically explored, and after the unfortunate experience at Braintree, their extent was reasonably well delineated before other work was started.

Investigation of the origins of Hammersmith have provided insight into the ways of the iron ore prospectors of the 17th century. The techniques were imported directly from England and the Continent.

Iron ore was identified by its yellow, brown, or reddish color, the color of its streak, and its luster, hardness, cleavage, and specific gravity, just as it is today. These early prospectors were vitally concerned with the grade of the ore and the impurities that it contained. Lacking analytical services, they judged the ore's value by grinding it with a mortar and pestle, heating the ground mass to a red heat, cooling the mass, and then by passing a lodestone (in place of a magnet) over it, evaluating the grade by the size of the portion that was attracted. The grinding and heating process was repeated with a flux added to liquify the melt, after which the metal was beaten out of the cooled mass. If the metal was not brittle or coarse, impurities in the ore were not excessive.

All the iron ore was mined in open pits, and most of it was bog iron. Approximately 3 tons of ore and 265 bushels of charcoal were required to make 1 ton of iron. The flux-to-ore ratio ranged from 0.40 to 0.60. Furnaces were tapped once or twice a day, and a run was 30 to 40 weeks.

Hammersmith operated for less than 30 years, but it provided a fountainhead of skilled iron workers for the New England Colonies, where, by 1700, no fewer than eight furnaces were working.

After the catastrophe at Falling Creek, the iron industry was dormant in the Southern Colonies until 1716, when the Spotswood furnace was built at Germania in Essex County, Va., about 20 miles above the falls of the Rappahannock River. The plant was built by German miners brought to the colonies to mine silver. The Spotswood furnace produced iron from a mixture of high-grade hematite, spongy limonite, and limestone from Bristol. The German miners quit shortly after the furnace was in full operation, and Spotswood operated it with slave labor. Altogether between 100 to 120 employees were needed for the operation, with women doing the cooking and farm hands raising corn for food and cutting hay for the mine oxen. The Spotswood furnace operated continuously and apparently successfully until 1750.

Contemporaneous with Spotswood, English ironmasters formed the Principio Co. of Maryland and blew in the Principio and Northeast blast furnace in Cecil County, Md., in 1724. The company started the Accokeek furnace in Stafford County, Va., in 1726 on land owned by Captain Augustine Washington. Iron from the Principio and Accokeek furnaces was sold in Liverpool, England, and its fame spread through the colonies and even to Europe.

Captain Washington became a member of the board of the Principio Company. On his death, the place passed to Lawrence Washington, George's half-brother. George was only 11 years old at the time, so it could have been age alone that prevented the first President of the United States from being a proprietor of one of the Nation's foremost iron and steel plants. The Principio Company has proved exceptionally durable. Wheeling Steel Co. traces its origin to it.

In 1730, 6 years after the Principio Co. was formed, Lord Sterling sent Cornelius Board to America, as his agent, to look for copper in the Ramabo Valley of northern New Jersey. Board did not find copper, but he found one iron deposit in the vicinity of what is now Ringwood, N.J., and another 5 miles to the north at Sterling, N.Y. These deposits played an important part in bringing the United States to its present position of eminence as a world power and as a producer of iron and steel.

The Ogden family bought the Ringwood property in 1740 and began mining and smelting iron ore there in 1741. The Ringwood mine was operated intermittently for 210 years. Its operators contributed greatly to the art and science of ironmaking as we know it today.

Peter Hasenclever, a German who operated Ringwood from 1764 to 1770, adopted a slate lining for the blast furnace, introduced a smelting method for recovering iron from old cinder banks, and was among the first to provide continuous power for the furnace draft.

Robert Erskine, the only formally educated civil engineer in the Colonies at the time of the Revolution, operated Ringwood from 1771 until his death in 1780. He is credited with inventing the magnetic separator. General Washington appointed him Surgeon General and Geographer in Chief of the Continental Army. Erskine made armaments for the Colonial armies during the Revolutionary War after telling the British owners: "I will look after your interest, but I am going to help the Rebels."

The furnace established at Sterling, N.Y., did not have operators as technically distinguished as those at Ringwood, but their service to America was every bit as great. Sterling contributed the iron chain used by the Revolutionary forces attempting to block the British from the upper Hudson River and forged the cannon and anchors for the frigates Constellation, Constitution, and Congress.

William Penn and Quaker conservatism held back the iron business in Pennsylvania to a certain extent, but even the earliest settlers had an interest in it, and it did not lag behind for long. Thomas Rutter made the first iron in Berks County in 1716 near Germantown on Manatawny Creek, 5 miles above Pottstown. Valley Forge, called Mt. Joy at the time, was built in 1751. The famous Cornwall furnace in the Cornwall hills on Furnace Creek in Lebanon County was built by Peter Grubb in 1742. Cornwall cast cannon and iron shot for the Continental Army.

Probably 60 blast furnaces were built in Pennsylvania between 1716 and 1776. The iron ore mining industry of the State grew by leaps and bounds through the transition from Catalan forges to charcoal and coal blast furnaces. It did not really slow down until the innovation of coke blast furnaces and the discovery of iron ore in the Lake Superior district. The first iron ore smelting furnace in the immediate Pittsburgh district was built in 1790, not far from what is now the Golden Triangle. The Pittsburgh district depended principally on pig iron from other areas until 1856.

Virginia, Maryland, and Pennsylvania produced

by far most of the iron in the American Colonies in the 18th century, but New England, New York, New Jersey, North and South Carolina, and the new State of Tennessee had successful iron mining and smelting industries. Even the fledgling Federal Government was in the iron smelting business in the 18th century, as army troopers built a smelting furnace on the Slate Branch of Licking River, 5 miles northeast of Owingsville, Ky.

The Revolutionary War forced Americans to depend on themselves, which helped the primary iron and steel industry at the time and did much to set the stage for rapid development later. After George Washington was elected President, and until trade was restricted for the 5 years preceding the War of 1812, no country advanced so quickly. The fruits of this period were invested in home industry during the trouble with England when goods could not be obtained from abroad, and by 1810 there were 530 iron furnaces, forges, and bloomeries operating in the United States. That year, the industry produced 53,908 tons of cast iron and 917 tons of steel, the total of which were valued at $12 to $15 million.

The war with England dampened temporarily the burgeoning iron industry, but not for long, and through the remainder of the first half of the 19th century it kept pace with that of England and Europe. By 1840 the U.S. industry had an invested capital of $20 million, operated 804 blast furnaces, employed 30,500 men, and produced 286,903 tons of cast iron and 197,200 tons of bar iron. It was dependent on open pit and underground iron ore mines close to the furnaces, since inexpensive transportation had not yet been developed.

Iron ore was discovered in the Lake Superior district in Michigan in June 1845 by Marje-Gesick, a Chief of the Chippewas. William Kelly began work on a process to decarbonize molten iron by blowing air through it at Eddyville, Ky., in 1850. Sir Henry Bessemer was perfecting an identical process in England; word of Sir Henry's work reached the United States in 1856. Robert Mushet developed spiegeleisen for deoxidizing and recarbonizing the Kelly-Bessemer air-blown metal. Sir William Siemens discovered the regenerative principle for heating in England in 1860, and Emile and Pierre Martin conceived the idea of charging scrap iron to dilute the impurities in pig iron in a Siemens furnace in France about 1868. Thus the Siemens-Martin process (the present-day open-hearth steelmaking process) came into existence. These events led to practically a revolution in the U.S. iron and steel industry.

The steel industry expanded westward. The Sault Ste. Marie ship canal was completed in 1845: thus the Great Lakes transportation system was opened to the heart of the iron mining country. Local iron mines were closed as higher grade, less costly ore became available through newly found distant mines and inexpensive transportation. Iron and steel and iron ore mining industries moved further apart, and for the first time it was possible to discuss the iron ore industry as a separate entity. Iron ore was discovered on the Mesabi Range at Mountain Iron, Minn., in 1890. It was first mined there in open pits by horse-drawn scrapers and hauled in wagons, but in 1893 a steam-powered shovel was brought in and railroads were built to the mines and into the pits.

By 1890 the technology of Kelly, Bessemer, Siemens, Martins, and Mushet was fully applied, and today it can truly be said that this metal, now common rather than precious, accommodates itself to all our wants, our desires, and even our caprices. In 1898 the United States surpassed all other countries in the production of iron ore with 19,433,716 tons. The great Mesabi Range had begun to fulfill its destiny.

The technology of iron smelting and steelmaking changed very little in the first half of the 20th century. It was fundamentally the same in 1950 as in 1900. The technology of iron ore mining and process, however, advanced steadily, stimulated by depletion of the high-grade deposits, and facilitated by the machinery of a maturing industrial age.

A magnetic concentrating plant was installed in the Lake Superior District in 1890, at the Groveland mine on the Menominee Range in Michigan. A jig concentrating plant was built at the Pewabic mine at Iron Mountain, Mich., in 1899. The Oliver Iron Mining Co. washing plant was built at Coleraine, Minn., in 1910. It was still operating in 1965. In 1911 there was a strong movement for the conservation of iron ore by washing, concentrating, roasting, and nodulizing and briquetting. By 1913 there was an obvious need to report crude and beneficiated iron ore in the industrial statistics, and beneficiated ore statistics were first reported in the Minerals Yearbook in 1914.

World War I gave tremendous impetus to U.S. iron and steel industries. Iron ore output reached a peak in 1916, but it declined in the second half of 1917 as the Federal Government became involved in pricing and rationing. It nose-dived in the latter half of 1918, when the steel mills ran out of coke, the mines were short of labor, and the

influenza epedemic practically shut down the entire industry. The United States was hit by a worldwide postwar depression. Iron ore production in 1921 was the lowest since 1904.

However, the boom and bust did not greatly affect the advance of iron mining technology. Large scale experimental work was started on the lean magnitite ores of the eastern Mesabi range in 1915. The Mesabi Iron Company, Argo mine plant at Babbitt, Minn., began shipping sintered magnetite concentrates in 1922. The concentrating plant was the forerunner of the present day Reserve Mining Co.'s Peter Mitchell mine at Babbitt and the E. W. Davis concentrator at Silver Bay, Minn., which was the first large-scale taconite operation in the United States.

The iron mining and steel industries changed from a 12- to an 8-hour day in 1923. In 1928 the automobile industry became the principal consumer of steel in the United States, with 18 percent of the total. The Great Depression of the 1930's hit hard in the iron mining camps. The industry produced less than 10 million tons of ore in 1932, less than in any years since 1886. At first recovery was slow, but the world armament race that started in 1936 put enormous demands on the U.S. iron and steel industry, and the industry has paused only momentarily since.

Heavy medium concentrators were introduced in iron ore mining at the Merritt plant at Ironton, Minn., in 1937. The Harrision concentrator, with two 7½-ft-diameter cones using ferrosilicon media, was built at Cooley, Minn., in 1939. In 1940, off-highway trucks were put in the iron ore pits, replacing some rail haulage. The "Minnesota taconite" law, which allowed special tax consideration for low-grade deposits, was passed in 1941. The MacArthur lock at Sault Ste. Marie was completed in 1943. Thus, at the end of World War II, the iron mining industry of the United States was in the best position ever, except that the great Mesabi range was running short of high-grade ore.

The U.S. steel industry was forced to search for new iron ore resources to support itself. A multibillion-dollar taconite industry was developed in the Lake Superior District, and iron deposits were discovered in Canada, Venezuela, Peru, and Liberia. The development of the taconite industry started a chain of events that have changed the iron mining and smelting industry as much in the last 20 years as it changed in its whole previous history. The taconite industry took over 40 years to develop. D. C. Jackling, who had gained renown as a pioneer in the large-scale mining of porphyry copper deposits, became interested in the taconite deposits in 1912. He and his associates conducted a drilling campaign of the deposits and metallurgical investigation of the ores in 1915 and 1916. They formed the Mesabi Iron Company and built an experimental mill and sintering plant at Duluth, Minn., in 1916. The experimental plant was closed in 1924, at the same time that the company's commercial venture at the Argo mine closed.

The Mesabi Iron Company's properties were taken over in 1939 through lease arrangements by the Reserve Mining Co., which was organized that year by Oglebay, Norton & Co. for Armco, Wheeling Steel Corp., Montreal Mining Co., and Cleveland Cliffs Iron Co., Republic Steel Corp. and Armco each acquired a 50-percent stock interest in 1951. The Reserve Mining Co. built a pilot pelletizing plant to treat taconite concentrates at Ashland, Ky., in 1948, and started construction of a 3.75-million-ton-per-year taconite pellet operation at the Peter Mitchell Mine at Babbitt and the E. W. Davis benefication plant at Silver Bay, Minn., in 1950. The mine and plant were completed in 1954. Their capacity was practically doubled by 1958, and increased to 9 million tons per year in 1961 and to 10.7 million in 1965.

Pickands Mather & Co., Bethlehem Steel Corp., and Youngstown Sheet and Tube Co. became interested in the low-grade Mesabi range deposits in 1931. After investigating and rejecting the lean oxide ores and a drilling campaign in the magnetite taconites, they formed the Erie Mining Co. to exploit the taconites in 1940. The Erie Co. established a taconite research laboratory at Hibbing, Minn. in 1942 and completed a 200,000-ton-per-year preliminary taconite pelletizing plant in 1948. The company started construction of a 7.5-million-ton-per-year taconite pellet plant in 1954. It was completed in 1957 and in 1967 was enlarged to produce 10.3 million tons per year.

A taconite industry developed in Michigan (the rock was called jaspilite there) at about the same time as in Minnesota. The Cleveland-Cliffs Iron Co. opened a modern research laboratory in 1949 at Ishpeming, Mich., to study means of concentrating that State's nonmagnetic lean ores. Researchers there subsequently developed a flotation process for concentrating the specular hematite deposits. On the basis of this successful research, Cleveland-Cliffs, with the Ford Motor Co., formed the Humboldt Mining Co., which completed a 650,000-ton-per-year concentrating plant in 1954. The Marquette Iron Mining Co.'s Republic plant, with

a capacity of 2.4 million tons per year, stemmed from Humboldt.

The Minnesota taconite industry stalled after the first start because of industrialists' hesitation to invest the vast sums necessary in a tax environment judged by past records to be risky. They had no such fear in Michigan, however, and the Empire Mining Co. plant at Empire with 1.2-million-ton-per-year capacity and the Hanna Mining Groveland plant with 1.25-million-ton-per-year capacity began operations in 1963.

Minnesota passed a semitaconite law in 1959, which stimulated large-scale research in the soft lean hematite ores, but it was not until a 'taconite" amendment to the State's constitution was approved in 1964, that the industry really started to move again. Immediately after that, mining companies announced that they would build taconite processing plants on the Mesabi range with total capacity to produce 10 million tons of high-grade taconite pellets per year.

Taconite pellets proved an immediate success with metallurgists operating blast furnaces. Their appetite for higher productivity had been whetted by the increased use of sintering and the better physical preparation of the entire burden. The pellet's structure proved equal or superior to that of sinter, and, in addition, its use increased furnace productivity in direct proportion to its relative iron content. By 1958, taconite pellets provided the standard by which all ores were judged. However, despite the emergence of the taconite industry after World War II, iron ore imports into the United States began a gradual increase in 1947.

U.S. companies looking for large high-grade iron ore deposits in foreign countries were spectacularly successful. In 1948, U.S. Steel announced the discovery of Cerro Bolivar in Venezuela, and M. A. Hanna Co. with Hollinger Consolidated Gold Mines, Ltd., reported 28 separate high-grade hematite deposits in the Labrador trough of Canada. In 1949, Republic Steel Co. became associated with the Liberian Mining Co., and the Export-Import Bank loaned the company the money needed for development of the Bomi Hills deposits in Liberia. High-grade ore from the Bomi Hills first reached the United States in 1952, from the Labrador trough in 1953, and from Cerro Bolivar early in 1954. Shipment from these properties marked the end of U.S. self-sufficiency in iron ore.

The Federal Government recognized the need for action to assure a continuing supply of iron ore to the domestic steel industry for both strategic and economic reasons, and through the Defense Production Act, passed in 1950, it provided rapid amortization for taconite plants and assistance for domestic iron ore exploration. Congress established the St. Lawrence Seaway Development Corp. in 1954, principally to facilitate imports of iron ore. Government officials periodically studied iron ore supply in relation to estimated wartime demands, and each time found that stockpiling was impractical considering the slight possibility of an ore shortage.

Science and engineering greatly strengthened U.S. industry in the first decade of taconite pellet production. Jet piercing machines using oxygen and fuel oil to put blast holes in the hard taconite rock were probably the most significant advance in the mines. But carefully engineered blasts, diesel and electric power to replace steam, and changing from 4-yard to 12-yard shovels and from 20-ton to 85-ton trucks probably contributed as much to mine productivity. Ore dressing and agglomerating techniques were refined and improved during this decade, but no one achievement stands out. Iron ore smelting techniques, of course, were greatly changed by the use of high-grade taconite pellets with almost perfect structure.

Bureau of Mines metallurgists working on cooperative projects with private industry developed an experimental blast furnace and proved its validity as a research tool. The experimental furnace was operated from 1958 until 1967. Its use was instrumental in the development of sized burdens, higher temperature blasts, high top pressure, and fuel injection into the smelting zone. Moreover, it provided the wherewithal to refine all phases of blast furnace operations.

The technique of injecting fuel into the smelting zone of the blast furnace was taken up rapidly in commercial operations. Lone Star Steel Co. installed the practice at its plant at Dangerfield, Tex. in 1959, and within 2 years fuel injection was the common practice in blast furnaces around the world.

The Bureau of Mines began investigating the reduction of taconite pellets in 1961, and an extensive treatise covering a process for prereducing pellets was published in Bureau of Mines Bulletin 651 in 1970.

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CHAPTER 2.—FORMS, PROPERTIES, CLASSIFICATIONS, AND USES

FORMS AND PROPERTIES
(Refer also to Geology Chapter)

Iron ore is a mixture of iron-bearing minerals containing varying quantities of mineral impurities. Naturally occurring forms, even though they differ in chemical and physical characteristics, are grouped together as iron ore because of their common iron content and mining profitability. Iron ore retains its identity through various processing procedures to ultimate use. As mined, and before any treatment, it is called crude iron ore. After being processed to final form, it is called usable iron ore, which is a misnomer from the 19th century when crushing and sizing were the only processes used to improve its quality. In a chemical analysis of usable ore from which the moisture has not been removed, the results are reported as iron ore, natural. If the moisture has been removed, the analysis is reported as iron ore, dried.

Iron ore is described according to its predominant iron-bearing mineral, or according to its color: hematite, magnetite, and occasionally goethite (limonite) and siderite; and (by color, respectively) red, black, and brown ores. Specular and micaceous, mineral forms characteristics, also are used to differentiate iron ores, particularly among the brown ores.

Silica is the prevalent impurity in iron ore, followed by alumina, silicates, lime, magnesia, titania, and minerals containing sulfur, phosphorus, and manganese. There has been a tendency to describe iron ore according to its rock type (or significant impurity), because, in the low-grade deposits exploited, rock types assume more significance than in high-grade deposits. Thus an iron ore can be siliceous, calcareous, manganferous, or titaniferous.

The term taconite was first used locally in Minnesota to designate hard, siliceous, banded rocks of the iron formations that occur there. Over the last 20 years it has come to be used to identify similar formations in other districts. Where taconite rock is mined for the contained iron, the ore is called taconite iron ore or simply taconite. Taconite ore in which magnetite is the principal iron mineral is described as magnetic taconite. If the principal mineral is not magnetite, the material is described as nonmagnetic taconite. Concentrated taconite, however, is simply taconite concentrate, without reference to the mineral type, unless there is a technical reason to distinguish between those that contain magnetite, hematite, and specularite.

Soft, partly altered taconite from which part of the silica has been leached by natural processes is called semitaconite. This term is most prevalent in the Lake Superior District. The State Legislature of Minnesota has described semitaconite as altered taconite ferruginous chert or slate in which the iron oxide is finely disseminated in particles smaller than 20 mesh, which is not merchantable in its natural state, and which cannot be made merchantable by simple beneficiation methods.

Jaspilite, a locally named iron formation rock of Michigan, and itabirite, a rock of Brazil's Minas Gerais District, are iron ores similar to taconite.

The particle size of natural iron ore ranges from natural lump particles crushed to pass an 8-in screen to fines that pass a ¼-in screen. Dense, massive ores which break into lumps when mined are called hard ores, and those yielding granular "earthy" products are called soft ores. Dense lump ore is often called open-hearth ore; hard ores sized to approximately ½-in often are classed as blast furnace lump.

The particle size of iron ore concentrate ranges from the approximate maximum dimension of the iron minerals downward to micron-size slimes. Fine-grained iron ore concentrate is processed (agglomerated) to form masses of a size suitable for smelting . The masses may be formed by sintering, briquetting, nondulizing, or pelletizing. The products (iron ore agglomerates) are called by their generic names: iron ore sinter, iron ore briquettes, iron ore nodules, and iron ore pellets (all further discussed in the next section).

Many golden-yellow and redish-brown mixtures of hydrated iron oxide minerals and clayey impurities, although not iron ore in the usual sense, are mined for use as paint pigments. They are called natural iron oxide pigments, and are graded by color and texture.

Pyrite and pyrrhotite minerals which have been calcined to remove the sulfur are designated as byproduct iron ore or iron ore cinder. These

minerals usually are produced as byproducts from base metal mines, but exceptionally rich pyrite deposits in favorable economic environments are occasionally mined for that mineral alone.

GRADES AND SPECIFICATIONS

In commercial transactions, iron ore grade and structure specifications are determined by negotiation between buyer and seller: they are set either by the consumers, who consider the types and quality of ore produced by mining districts serving them, or by mines producing ore competitively offered for sale to many customers. Consequently, there are many grades of iron ore and universal specifications. The acceptable grades and impurity levels of commercial ores vary widely from country to country, and in several countries, from one mining district to another. However, since the use of iron ore in a blast furnace narrows the allowable variation in its structure, specifications for physical characteristics tend to be about the same the world over. Invariably, impurity limits and structural requirements are more rigid than iron content.

In the United States, iron ore market transactions are keyed to a classification of iron ores, based on iron analysis and phosphorus content, which was adopted by the Lake Superior District iron mining industry in 1925. The original classification is still valid for natural ores and concentrates. It is as follows:

Type of ore [1]	*Phosphorus content, percent*
Old Range bessemer	.045
Old Range nonbessemer	.045
Mesabi bessemer	.045
Mesabi nonbessemer	.045
High Phosphorus	.180

[1] Base analysis 51.5 percent iron, natural.

Ores containing .045 percent phosphorus or less are classed bessemer, those containing more than .045 percent phosphorus are classed nonbessemer, and those containing more than .180 percent phosphorus are classed high phosphorus. Ores containing more than 2 percent manganese are classed manganiferous, and those containing more than 18 percent silica are classed siliceous. Hard ores high in iron and low in silica are often classed Old Range nonbessemer.

The base prices of Lake Superior iron ores have been established and published annually in the trade journals for many years by the ore merchants. They are based on the value per long ton of ore containing 51.5 percent iron, natural (and base value) at lower lake ports. The long or gross ton (2,240 pounds) is the normal unit of measure used by the iron ore industry in the United States and Canada. The metric ton (2,205 pounds) is used in most European countries. Unless otherwise noted, tons in this publication refer to long tons.

If, for exemplary purposes, $10 per long ton of 51.5 percent iron ore is used as the base value, the base unit value (where a unit is one percent) is:

$$\$0.1942 = \frac{\$10}{51.5} \qquad (1)$$

For any ore containing 50 percent or more iron:

$$\$\text{—.——} \text{ per long ton} = \text{percent iron} \times \$0.1942 \qquad (2)$$

For any ore containing 49 percent or more iron, but less than 50 percent iron:

$$\$\text{—.——} \text{ per long ton} = \$10 - \$0.1942 \left[(1.5)\ (1) + (1.5)\ (\text{fraction of unit below 50 percent})\right] \qquad (3)$$

Derivation from equation 2 due to economic factors.

For any ore containing less than 49 percent iron:

$$\$\text{—.——} = \$10 - \$0.1942 \left[(1.5)\ (1) + \underset{\text{to 49 percent}}{\text{Correction}} (1)\ (1.5) + (2)\ (\text{units or fraction thereof of below 49 percent})\right] \qquad (4)$$

Additional deviation due to further economic adjustment.

Economic adjustment means that not only is an ore worth proportionately less because of its lesser iron content, but also that that iron is harder and therefore more costly to extract, and so worth less to the processor. Iron ore having exceptional lump structure or high manganese content commands premium prices which are negotiated between buyer and seller.

Since the iron ore agglomerate structure is fundamentally different from that of natural iron ores and concentrates, as they came on the market each established a distinct class of iron ore. The agglomerates have been identified by their producing company or processing plant, plus their generic name. Thus, Erie pellets, Reserve pellets, and Cliffs pellets were produced by the Erie, Reserve, and Cleveland Cliffs iron mining companies, respectively. Extaca iron ore nodules and iron ore sinter were produced at the Oliver Iron Mining Co. (formerly a division of U.S. Steel) Extaca

plant. Individual pellet classification according to origin has not been common since 1961, because all pellets reaching the market have had similar physical characteristics and have met minimum durability standards.

Currently iron ore pellet is a class of iron ore that is priced according to its iron content, measured in long ton units. Lake Superior pellet price per unit iron natural at lower Lake Ports is published with the other iron ore quotations. Reducibility, porosity, bulk density, crushing strength, and durability are significant properties of pellets.

Pellets have not been on the market long enough for complete classification according to standard U.S. specifications, but means have been devised for measuring the significant properties. Acceptable values for crushing strength and durability have been established by experience.

Porosity is measured by percent voids, bulk density is measured in pounds per cubic foot, and crushing strength is measured in pounds per square inch. All are measured with ordinary physical laboratory equipment using standard procedures.

Reducibility has been measured as the time in minutes required to achieve 90-percent reduction in an atmosphere of hydrogen.(*1*) Durability is measured by the standard tumbler test for iron ore pellets and sinter; a tentative test for compressive strength of iron ore pellets is used also.

The Japanese steel industry has established standards for international use in the purchase of iron ores and pellets. These are coordinated by the Japan Standards Association as the Japanese Industrial Standards (JIS) similar to the ASTM Standards, and include a tumbler index.

Pellets with the following characteristics can withstand ordinary handling and have proved suitable for use in a blast furnace:

Diameter	½ inch
Porosity	29 percent
Bulk density	120 to 140 lb per cubic foot
Crushing strength	300 to 1200 lb per square inch
Reducibility (90-percent reduction)	64 minutes
Durability (ASTM tumbler test)	85 to 98+

Chemical and physical characteristics of the iron ore sinters and nodules vary markedly from one producer to another. Consequently, sinters and nodules invariably are identified by their point of origin. Few are sold on the open market. Most of the sinter in the world is produced by integrated steel plants, each plant establishing specifications or standards according to its mode of operation. Most strive for a minimum of fines and good reducibility. Therefore, porosity, crushing strength, and durability are the significant characteristics for sinter, just as for pellets. In contrast to pellets, however, the acceptable values established by experience have not been publicized. Each steel plant produces iron ore sinter of the quality needed to satisfy the metallurgical requirements of its smelting operation with minimum cost, usually utilizing all the iron-bearing flue dust and mill scale it generates.

Iron ore briquettes are a substitute for dense lump, open-hearth ore. Most have been made of high-grade fines with a pillow shape, about 4 by 6 inches. Standard specifications have not been established, but briquettes must be durable enough to withstand handling and must have a high enough specific gravity to sink in the bath of an open-hearth furnace. The specific gravity should preferably be more than 5.0.

ASTM has established various specifications for the natural iron oxide pigments. They are similar in that iron content and impurity limits are prescribed, but each has individual color, tinting, and oil absorption requirements. ASTM specifications for raw sienna and umber are as follows:

Raw sienna
(ASTM designation D765–48)

	percent
Iron oxide (Fe_2O_3), minimum	38
Calcium compounds (as CaO), maximum	5
Moisture and volatile matter, maximum	4
Coarse particle, residue on 325 screen, maximum	2
Organic colors	0

Raw umber
(ASTM designation D763–48)

	percent
Iron oxide (Fe_2O_3) minimum	37
Calcium compounds (as CaO), maximum	5
Moisture and volatile matter, maximum	5
Coarse particle, residue on 325 screen, maximum	2
Organic colors	0

USES OF IRON AS A PRIMARY CONSUMER GOOD

Use of Iron Ore as a Source of Iron

More than 93 percent of the iron ore consumed in the United States is smelted in blast furnaces. For this purpose it is selected or blended to provide uniform chemical characteristics. Modern practice is to grade and size the ore and reject the fine-grained material with diameter less than ¼ inch. Iron ore pellet and sinter are designed as a uniform product for the blast furnace and therefore usually provide the best feed. However, carefully sized and graded ore with a porus structure that provides a large surface area is equally good if the grades are comparable.

Iron ore pellet is generally considered better than iron ore sinter, in that it provides a high rate of production with a minimum of fuel. However, there are metallurgists in Europe and Japan who prefer their own sinter to pellet because they have better control of the fines.

All iron ores have impurities that must be removed in the smelting process. Oxides of the basic metals—calcium, magnesium, sodium, potassium, all the rare earth oxides, and alumina—are not reduced in the furnace, so they do not directly affect the composition of the iron. They do not cause a smelting problem, and calcium, magnesium, and aluminum (up to 5 percent alumina) are fluxes and may be valuable as such. But silica, silicates, sulfates, selenates, titania, and compounds of maganese, chromium, vanadium, cobalt, columbium, and zirconium are partially reduced, so these metals enter the molten iron unless they are removed as compounds in the slag.

Compounds of arsenic and phosphorus are always reduced. Phosphorus is especially objectionable since it is present in most ores and cannot be completely eliminated from the blast furnace hot metal. Arsenic occurs rarely in iron ores; when it does it acts similarly to phosphorus.

Iron ores in which the impurities are acidic and basic in approximately equal proportions are termed self-fluxing ores. These are more valuable for use in a blast furnace than siliceous ore of equal iron content because the addition of lime necessary to neutralize the ore dilutes the charge.

In many respects iron ore destined for direct reduction processes must have the same characteristics as blast furnace ore. Iron content and reductibility are equally important. Impurity limits are just as stringent as a rule, but since the reducing atmosphere is not as strong, the elements that are partially reduced in a blast furnace do not cause as much trouble in direct reduction. Silica is the worst offender if it is very fine grained. The silicates and titania seldom are objectionable. However, in some direct reduction processes silica and alumina cannot be rejected and the total gangue content must be very low.

Electric furnaces are used to smelt iron ore in some areas where the cost of coke is high and that of electric power is low. If other carbon fuels are available for heat more cheaply than electric power, the iron ore may be dried, or even partially reduced, before reaching the electric furnace. Physical and chemical specifications for the ore may not be quite as stringent as for a blast furnace, but the grade should be the highest obtainable. High-grade titaniferous iron ore that is low in silica can be smelted in an electric furnace to produce pig iron and a slag valuable for its titanium content.

Iron ore that is to be reduced in a fluidized bed must be fine grained. For other types of direct reduction, the structure is not more critical than for a blast furnace. Lump or pellet is preferred for most of the direct processes.

Iron ore is used in the basic open-hearth steelmaking furnace for the oxygen it contains. The iron is obtained principally from scrap and blast furnace hot metal. The oxygen of the ore reacts with carbon to form carbon dioxide that escapes as a gas, causing the bath to boil turbulently. Oxygen reacts with silicon, manganese, and phosphorus to form solids that must be removed in the slag. Therefore, basic open-hearth ore should not be siliceous, or additional limestone must be added to prevent the acidic slag from corroding the furnace lining.

Phosphorus combines with lime to form calcium phosphate $(CaO)_3.(P_2O_5)$. This is a stable compound in the presence of oxygen, but the phosphorus will return to the metal if there is an oxygen deficiency in the bath. So phosphorus is as undesirable in basic open-hearth ore as it is in blast-furnace ore. Iron ore is not used in an acid open-hearth furnace because iron oxides are basic and would corrode the lining.

Open-hearth ore should be in lumps dense enough to sink through the slag and float in the metal. Iron ore briquettes and dense pellets can be used in place of the lump ore, but neither is as satisfactory.

Iron ore is used occasionally for cooling in Bessemer converters. The quantity used is small, but for an acid converter it must not contain more than 0.045 percent phosphorus. Basic converters take care of phosphorus in the same manner as

basic open-hearth furnaces. If sulphur is present, its oxidation provides part of the heat. Iron ore is not used in either type of converter if other coolants are readily available.

Normally iron ore is not used in oxygen steelmaking furnaces, but the chemistry of the processes is the same as in Bessemer converters. Oxygen furnaces are characterized by their efficient use of heat, so there is seldom reason to cool the bath.

Iron ore carrying 40 to 48 percent iron with 20 to 30 percent silica and virtually no other constituents except water and combined oxygen is used to make silvery pig iron, a low-silicon alloying metal. Combinations of iron ore and quartzite are smelted together in electric furnaces to make ferrosilicon with varying ratios of iron to silicon. Occasionally ferromanganese manufacturers use iron ore to adjust their product to standard specifications, and ore of varying quality has long been used as a basic flux in nonferous smelters.

Use of Iron Ore for Its Physical Properties

Iron ore is used in concrete where high density is needed. Concrete covering for underwater pipelines and footings of exceptionally high steel structures often are made from coarse and fine magnetite-mineral aggregates. Lump magnetite has been used for ship ballast.

Concrete for structures housing nuclear installations is often made from magnetic iron ore because magnetite minerals shield against atomic radiation. Magnetite ore is used in heavy-media ore dressing and in coal-washing plants, but ferrosilicon has supplanted it in virtually all the iron-ore concentrators.

Jewelers' rouge is a special grade of hematite, and certain species of specular hematite are used in paints for their physical rather than their coloring characteristics. Paints containing these hematites are noted for their covering and protective qualities.

Use of Iron Ore for Its Chemical Properties

Manufacturers of portland cement use iron ore as an additive material when the normally used raw materials have insufficient iron oxide. Iron oxides perform complex chemical functions, replacing alumina in some compounds and influencing thermal effects during processing. Similarly, iron ore is used in some basic refractories for its chemical influence on the process and product.

Iron is a necessary constituent of most plant and animal life. Iron-enriched fertilizers are needed in some areas; the iron may be supplied from iron ore after chemical alteration to render it soluble. Stock feeds often require mineral supplements including iron. Iron-enriched medicines frequently are prescribed for humans to improve their general health.

High-grade iron ore concentrate is a raw material for the chemical plants that produce pure iron oxides. Iron carbonyls, the intermediate products, are used for producing high-purity iron and ferrites used in the electronics industry.

Use of Iron Ore for Its Pigment Properties

Perhaps the oldest use of natural iron oxides is for coloring materials. Primitive peoples, notably American Indians, used soft clayey iron ores for war paint and ceremonial decoration. Paintings in caves occupied by ancient people included ochres, umbers, and siennas that have retained their brightness through the ages. Hematite is red with color variations due to impurities. Ochre is the hydrated yellow oxide of iron shading into brown (sienna and umber), with increasing content of manganese oxide. Some of the criteria for determining pigment-quality iron ores are color, tinting strength (ability to influence color in a standard paint or other medium), fineness of grain, oil absorption, and chemical analysis.

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CHAPTER 3.—GEOLOGY AND RESOURCES

GEOLOGY AND MINERALOGY

Iron Ore Minerals

Iron oxides are the most significant mineral components of iron ores; but iron carbonates, hydrated iron silicates, and iron sulfide minerals also form ores in exceptional economic environments. The common iron ore minerals in order of descending economic significance are listed in Table 1.

Iron Ore Deposits

Iron ore deposits are bodies of iron minerals of such a nature and so situated that they can be mined profitably. They may be categorized according to their genesis, their physical structure, their geologic features, or their amenability to metallurgical processes.

In the geologic sense, any mass of iron ore minerals comprises an iron ore deposit whether or not it can be exploited profitably. There are three general types, (1) bedded, (2) massive, and (3) residual. Bedded deposits are sedimentary strata that have accumulated in bodies of water. Massive deposits are masses or veins of iron minerals that have replaced preexisting minerals or have filled the voids in existing rocks. Residual deposits are bodies of iron minerals that have been formed by decomposition of iron-bearing rocks from which some or all the nonferrous constituents have been removed.

These general types may be differentiated on the basis of mineralogy. Thus each type may be classified as hematite, goethite, siderite, or combinations thereof such as, hematite-magnetite, hematite-goethite or magnetite-goethite. Physical structure of the minerals and the physical characteristics of these ore bodies can be used further to differentiate iron ore deposits in the geologic sense. However, some geological classifications are complex and require skilled scientific evaluation of mineral and rock genesis for their use.

Classification of Deposits

A combination of geologic and empirical data was used to classify iron ore deposits for a worldwide survey of iron ore resources in 1954. This classification, which was modified and expanded for a similar survey in 1968, overcomes most objections to a classification based on strictly geologic criteria. See Table 2.

The characteristic features of different types of bedded iron formations are as follows: [2]

1. *Lake Superior.*—Interbanded chert or quartz and iron minerals with prominent granular or oolitic textures; associated with dolomite, quartzite, black carbon-bearing shales and slate, chert breccias and volcanic rocks; usually well-defined formations of broad regional extent; form in continental shelf and miogeosynclinal environments. Extensively developed in late Pre-Cambrian rock groups; often highly metamorphosed. Examples: deposits in Lake Superior and Labrador iron ranges. Lake Superior type bedded iron deposits were further delineated as follows:

(*a*) *Primary.*

[2] Mineralization data are from Gross (2); other characteristics are from the United Nations' Department of Economic and Social Affairs Survey (5).

Table 1.—Common iron ore minerals in order of descending economic significance

Mineral	Composition	Iron percent	Specific gravity	Color
Hematite	Fe_2O_3	69.9	5.2	Grey to red.
Magnetite	Fe_3O_4	72.4	5.2	Black-blueblack.
Geothite	$Fe_2O_3.H_2O$	62.9	4.3	Yellow-blackish brown.
Siderite	$FeCO_3$	48.2	4.0	Grey-brown.
Pyrite	FeS_2	46.5	5.0	Brass.
Marcasite	FeS_2	46.5	4.9	Light brass yellow.
Pyrrhotite	$Fe_{(1-x)}S$	60-63	4.5-4.6	Bronze yellow.
Chamosite	$(Mg, Fe, Al)_6 (Si, Al)_4O_{14}(OH)_8$	33-42	3.0-3.5	Green to light yellow.

Table 2.—Iron ore resources of the United States: Summation by type of ore deposit
(Million long tons)

Resources	Lake Superior region	North-western region	South-western region	Central-Gulf region	Central-Western region	Western region	Alaska	Hawaii	Total
Bedded:									
Lake Superior	76,799	---	---	---	1,335	221	---	---	78,355
Algoma	304	317	---	---	---	---	---	---	621
Clinton	---	595	2,072	---	67	---	---	---	2,734
Iron sands, aluvials, etc.	---	---	---	---	2	295	---	---	297
Other and not classified	---	---	492	---	36	---	---	---	258
Subtotal	77,103	912	2,564	---	1,440	516	---	---	82,265
Massive:									
Magnitnaya	---	59	---	---	433	307	11	---	810
Kiruna	---	268	---	309	---	34	---	---	611
Taberg	---	120	---	1	275	10	11,269	---	11,675
Other and not classified	---	10	---	---	---	---	---	---	10
Subtotal	---	457	---	310	708	351	11,280	---	13,106
Residual:									
Laterite	---	---	---	---	---	12	---	1,025	1,037
Other and not classified	2	---	2,245	163	4	---	---	---	2,414
Subtotal	2	---	2,245	163	4	12	---	1,025	3,451
Not classified	---	---	4,483	174	99	---	---	---	4,756
Total	77,102	1,369	9,292	647	2,251	879	11,280	1,025	103,578

Sedimentary beds, minerals in various stages of recrystallization. Others names in use:
Itabirite.
Taconite, metataconite.
Jaspilite.
Iron-quartzite.

(*b*) *Enriched.*

(1) Enrichment of iron in sedimentary beds by geological processes, mainly hematite and geothite ores.

Examples: Mesabi Range, soft ores; Brazil—Minas Gerais, high-grade hematite ore; Venezuela—Cerro Bolivar deposit; Knob Lake area deposits—Labrador and Quebec, Canada; Krivoy Rog, Ukrainian SSR, oxidized ores.

(2) Semitaconite, oxidized and partly enriched cherty iron beds; Wash ore.

(3) Canga—derived from types b-1 and b-2; Rubble ore—derived from types b-1 and b-2.

2. *Algoma.*—Thin-banded chert or quartz and iron oxides, silicates, carbonates and sulphides, associated with volcanic rocks and greywacke; usually in thin lenses with streaky banding; oolitic textures absent or inconspicuous; relatively rare but in rocks of all ages, especially early Pre-Cambrian; eugeosynclinal. Examples: deposits in Moose Mountain and Michipicoten area, Algoma district, Ontario, Canada; Western Australia. These were further described as—

(*a*) *Primary.*

Sedimentary beds, minerals in various stages of recrystalization.

Examples:
Michipicoten, Ontario, Canada.
Soudan, Minnesota, United States.
Moose Mountain, Ontario, Canada.
Many iron formations in Archaean rock belts in Australia and Canada.

(*b*) *Enriched.*

Enrichment of iron in sedimentary beds by geological processes.

Examples: Soudan Mine, Minnesota—hard hematite.
Old Helen Mine, Michipicoten—hematitite and geothite.
Steep Rock Lake, Ontario, Canada.

3. *Minette.* — Siderite-chamosite-iron silicate and goethite beds; usually high in phosphorus; oolitic textures; lenticular beds containing clastic material, sideritic mudstones and concretionary siderite layers; associated with sandstones, carbonaceous shales, siltstone and limestone; cyclic sedimentation of sandy beds, shale and ironstones and

Table 3.—Iron ore resources of the United States: Summation by type of mineral

Reserves			Potential ore			
Type of mineral [1]	Quantity, million long tons	Fe range, percent	Type of Mineral [1]	Quantity, million long tons	Fe range, percent	Total resources million long tons
LAKE SUPERIOR REGION						
Hematite	299	37-61	---	---	---	299
Goethite	2	47	---	---	---	2
Hematite-magnetite	1,923	26-61	Hematite-magnetite	[2] 60,381	22-60	62,304
			Hematite-siderite	49	56-59	49
Hematite-magnetite-siderite	4	26-33	Hematite-magnetite siderite	10,088	20-33	10,092
Hematite-magnetite-goethite-siderite	28	43	Hematite-magnetite-goethite-siderite	4,331	43	4,359
NORTHEASTERN REGION						
---	---	---	Hematite	595	23-50	595
Magnetite	80	26-42	Magnetite	145	22-65	225
Hematite-magnetite	20	42-62	Hematite-magnetite	213	22-68	233
---	---	---	Hematite-magnetite-goethite	317	17-21	317
SOUTHEASTERN REGION						
Hematite	21	20-55	Hematite	2,500	17-55	2,521
Goethite	724	20-57	Goethite	18	23-54	742
Hematite-magnetite	22	47	Hematite-magnetite	22	47	44
Hematite-goethite	2,200	23-60	Hematite-goethite	3,786	23-40	5,986
CENTRAL-GULF REGION						
Magnetite	207	52-56	Magnetite	1	50	208
Goethite	1	50	---	---	---	1
Hematite-magnetite	98	55	---	---	---	98
			Hematite-goethite	4	10-40	4
Goethite-siderite	337	17-48	---	---	---	337

black shale common; formed in transition zones between marine-and brackish-water environments. Most common in Mesozoic and younger rocks. Examples: Jurassic beds in England; minette ores of Lorraine, France, Luxemberg and Belgium; deposits in Peace River area of Alberta, Canada. These Ironstone-formation, minette type, marine deposits were described as—

(*a*) ***Primary.***

Sedimentary beds—
Examples:
Lorraine Basin, France.
Luxembourg—Salzgitter type sediments.
Federal Republic of Germany—Minette type, nonmarine.

(*b*) ***Enriched, by geological processes.***

4. *Clinton.*—Hematite-chamosite-siderite formations; interbedded with carbonaceous shale, carbonate rocks and sandstones; high in phosphorus, compared with cherty formation; oolitic to granular texture; miogeosynclinal and shallow-basin environments; lenticular beds restricted to thin

Table 3.—Iron ore resources of the United States: Summation by type of mineral—Continued

Reserves			Potential ore			
Type of mineral [1]	Quantity, million long tons	Fe range, percent	Type of Mineral [1]	Quantity, million long tons	Fe range, percent	Total resources million long tons
CENTRAL-WESTERN REGION						
Hematite	62	25-35	Hematite	5	23-26	67
Magnetite	416	22-35	Magnetite	266	15-49	682
Goethite	3	46-55	Goethite	1	20-58	4
Hematite-magnetite	405	26-68	Hematite-magnetite	596	28-68	1,001
Hematite-goethite	12	28-44	---	---	---	12
Magnetite-goethite	57	30-67	Magnetite-goethite	197	30-32	254
Goethite-siderite	1	19-38	---	---	---	1
Hematite-magnetite-goethite	101	---	Hematite-magnetite-goethite	98	9-55	199
Hematite-goethite-siderite	30	55	---	---	---	30
WESTERN REGION						
---	---	---	Hematite	15	43-46	15
Magnetite	20	34-46	Magnetite	305	5-26	325
Goethite	3	39	Goethite	1	39	4
Hematite-magnetite	355	30-60	Hematite-magnetite	99	21-60	454
Hematite-goethite	5	48	Hematite-goethite	21	35	26
Hematite-magnetite-goethite	54	30-60	Hematite-magnetite-goethite	2	33	56
ALASKA						
Magnetite	7	50	Magnetite	11,271	15-24	11,278
Hematite-magnetite	1	50-65	Hematite-magnetite	1	50-65	2
HAWAII						
---	---	---	Hematite-magnetite-goethite	1,041	22-39	1,041
---	---	---	Goethite	140	19-52	140

[1] The order of mineral combinations does not necessarily reflect descending order of abundance.
[2] Includes an undetermined amount of hematite-magnetite-siderite from the Menominee Range.

formations of broad regional extent as in the Appalachian belt. Most common in rock groups of Cambrian to Devonian age. Examples: deposits at Birmingham, Alabama; Wabana, Newfoundland, Canada.

These Clinton type ironstone-formation deposits were further described as—

(*a*) *Primary.*

Examples:
Birmingham, Alabama, United States.
Wabana, Newfoundland, Canada.

(*b*) *Enriched, by geological processes.*

Original deposits mined in Clinton beds, Alabama, United States.

5. *Black-band ores and non-oolitic beds.*—A heterogeneous group of non-oolitic, lensy ferruginous beds varying in composition and type from the

black-band sideritic carbonaceous claystones associated with coal, to the Lahn and Dill hematite and goethite beds locally rich in manganese and/or silica, to siderite-iron silicate-goethite lenses in shale. Associated with fine-grained clastic or volcanic rocks; occurring mainly in late Palaeozoic and younger rocks. Examples: deposits at Gross Ilsede and Peine, Lower Saxony, Federal Republic of Germany.

Back-band ores (non-oolitic textures, massive beds) are further delineated as—

(*a*) *Primary.*

Examples:
United Kingdom.
Federal Republic of Germany.

(*b*) *Enriched, by geological processes.*

6. *Ferruginous Sandstone and Shale (Consolidated).*—Placer deposits of black sands; mainly magnetite with siderite or hematite in sandstones, usually contain titanium and rare earth elements; thin beds of lensy distribution, varied grade and quality; deposited along beaches or near shore marine environments.

Ferruginous sandstone and shales are further delineated as—

(*a*) *Primary.*

Consolidated sediments.
Examples:
Alabama, United States.
Tennessee, United States.
Burmis, Alberta, Canada.
Braemar iron formation, Razorback Ridge, Australia.

(*b*) *Enriched, by geological processes.*

7. *Ferruginous Sands.*—Gravels, placers, alluvial and unconsolidated clastic sediments.

Examples:
Angola.
New Zealand.
Hokkaido, Japan.
Romori, Japan.
Natashquan, Quebec, Canada.

8. *Ferruginous Carbonate beds.*—

(*a*) *Primary.*

(*b*) *Enriched, by geological processes.*

Characteristic features of different types of massive iron deposits are as follows: [8]

1. *Bilbao type.*—Massive, irregular discordant masses of goethite and hematite or siderite replacing limestone or dolomite; usually iron-oxide minerals occur above the water-table and siderite below; ore textures vary from compact, massive, botryoidal to soft and friable; phosphorus content usually low, manganese content varies; and lead, zinc and copper-sulphide minerals, along with arsenic, fluorite or barite, may be present in significant quantities.

Massive iron oxide deposits derived from the weathering of underlying iron carbonate. Iron deposits of irregular shape occurring as iron carbonate below the water-table and as goethite and hematite above the water-table.

Examples:
Bilbao, Spain.
Cumberland, England.
Erzberg, Austria.

2. *Magnitnaya type.*—Commonly referred to as contact-metasomatic type; composed mainly of magnetite with lesser amounts of hematite and carbonate, pyrite, pyrrhotite and chalcopyrite commonly disseminated; deposits of magnetite occur as irregular massive bodies, pods, disseminations, replacements or veins in or near the contact zones of granodiorite, syenite or granitoid intrusions in limestone, amphibolite, basic extrusive rocks, tuffs and sediments; magnetite is associated with and often replaces skarn mineral assemblages present in those contact zones, which are commonly composed of lime and magnesium-rich silicates, such as garnet, pyroxene, amphibole, epidote, zoisite and chlorite; apatite crystals are disseminated in some deposits.

Massive and vein iron deposits, mostly magnetite and hematite but sometimes with carbonate and pyrite and often with associated skarn minerals: they occur mainly in limestone, volcanic-sedimentary basic rocks and amphibolite, but occasionally in other rocks, and are associated with igneous masses. Occur characteristically in irregular masses and veins. Frequently referred to as contact metasomatic type.

Examples:
Mount Magnitnaya, Ural Mountains, U.S.S.R.
Marcona, Peru.
Cornwall, Pennsylvania, United States of America.

3. *Kiruna type.*—Massive magnetite deposits which appear to be intrusions in granitoid and syenite rocks; characterized by a high magnetite content and appreciable apatite; deposits form massive tabular to irregular dike-like bodies, complex stockworks or vein-like masses.

Massive magnetite intrusions, usually associated with granitoid of syenite type, characterized by a relatively higher apatite content.

Examples:
Kiruna, Gallivare and Grangesberg, Sweden.
Cerro de Mercado, Mexico.
Pea Ridge, Missouri.

4. *Taberg type.*—Massive and disseminated deposits of titaniferous magnetite and ilmenite syngenetic or epigenetic in gabbro, anorthosite and basic igneous and metamorphic rocks; titanium present in magnetite crystal lattice, as exsolved blades in magnetite and in ilmenite; irregular massive magnetite bodies appear to be intrusions or injections in gabbroic host rocks; disseminated

masses of magnetite, appear to be syngenetic in gabbro and pyroxenite rocks.

These are further delineated as follows:

(a) Massive and disseminated titaniferous magnetite deposits associated with basic and ultrabasic rocks, commonly syngenetic in their host rocks or epigenetic.

(*a*) *Massive and disseminated titaniferous magnetic deposits associated with basic and ultra-basic rocks, commonly syngenetic in their host rocks or epigenetic.*
Examples:
Taberg, Sweden.
Lake Sanford, New York, United States.
Kachkanar, Ural Mountains, U.S.S.R.

(*b*) *Massive and disseminated ilmenite deposits, analogous to* (*a*).
Examples:
Alard Lake, Quebec, Canada.

Residual Deposits include the following:

1. *Laterites.*—Blanket deposits of iron oxides derived from decomposition of underlying rocks, including bauxites.
Examples:
Conakry, Guinea.
Mayari, Cuba.
New Caledonia.

2. *River-bed deposits and bog iron.*—Iron transported in solution or a colloid and precipitated in river-beds, in surface depressions or on slopes.
Examples:
Lisakov, Kustanai area, U.S.S.R.
Robe River, Australia.

3. *Other residual deposits.*—Local surface concentrations of iron oxide, derived from decomposition of underlying massive rocks, including gossans, iron sulphide deposits and float ore. These are distinguished from iron deposits formed by the enrichment of iron sediments.

Byproduct iron is recovered as follows: Iron or iron products recovered as byproducts in the processing of ores of elements. The resources of iron which may be calculated in deposits when iron or iron products are recovered in the processing of ores from deposits not otherwise classified in this list.

Another type of deposit is found at El Laco, Antofagasta, Chile. It is described as related to pleoscene volcanic activity. The ores consist almost exclusively of magnetite and hematite with a gangue of quartz, actinolite, scapolite, and small gains of apatite. They closely resemble a basalt flow. (Ed. note.—This section amplified by the Bureau of Mines.)

The geologic-empiric classification has proved useful in cataloging all types of deposits and it has been generally accepted by those in the mineral professions for this purpose. It has not been satisfactory to Government officials, legislators, investors, industrialists in iron and steel, or to those industrial concerns that supply the iron and steel industries.

The problem of classifying mineral deposits in a way that is universally accepted is not peculiar to iron ore. Classifying, evaluating, and cataloging mineral resources is invariably difficult. Mine operators solve the problem by measuring mineral deposits with an accuracy balanced against the cost of obtaining the necessary information, and accepting a calculated risk for less than perfection. Their interest is in commercial ore, and hence they consider as resource material only those deposits that can be mined profitably at the time of evaluation, or in the foreseeable future. The profitable resources, in the mine operators lexicon are proved, probable, and possible reserves, or analagous terms that serve the purpose as long as the user is sufficiently informed to recognize their limitations. Reserve figures are valid within the range of current and anticipated economic conditions. They are adequate for an entrepreneur planning to open a property and for the mine operator that follows. The proved classification refers only to a degree of knowledge, because at no time is the precise size of a mineral reserve known until it is mined.

The Bureau of Mines and the Geological Survey, after a joint study, found that the terms proved, probable, and possible, with the implied relationships between them, left much to be desired and agreed to use the terms measured, indicated, and inferred in all joint Survey-Bureau reports. (*4*)

Standard definitions for the three categories are as follows:

Measured Ore

Measured ore is ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are so closely spaced and the geologic character is so well defined that the size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within stated limits, and no such limit is judged to differ from the computed tonnage or grade by more than 20 percent.

Indicated Ore

Indicated ore is ore for which tonnage and grade are computed partly from specific meas-

urements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout.

Inferred Ore

Inferred ore is ore for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition for which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred ore should include a statement of the spatial limits within which the inferred ore may lie.

In this context ore means only material that can be mined at a profit. The categories are satisfactory for enumerating the reserves of individual properties and they can be used to arrive at a meaningful total of iron-ore reserves in a district or combinations of districts to cover any area under consideration. The only objectionable feature is that reserve estimates tend to be ultraconservative when they are made for entire countries, for continents, or for the world as a whole.

RESOURCES

The reserve classifications have never satisfied those who must evaluate a mineral position over a long period of time. These people need to know the probable reserve position for a wide range of economic changes. If the value of a mineral increases—will its reserve increase in proportion; and conversely as value decreases will the reserve decrease in proportion?

The problem has been partially resolved by taking protore, or marginal ore into consideration, "marginal" in this instance meaning something less than economic. Then the total of marginal ore and ore reserves is designated a mineral resource. Blondel and Lasky (*1*) probably did more to formalize this exercise than most. They suggested referring to resources as being equal to reserves plus potential ores. If the potential ores varied widely in quality, they would be grouped as "marginal resources," "submarginal resources," and "latent resources." They recommend that the terms "measured" and "indicated" be abandoned and replaced by a single term that would include them both, and suggested "demonstrated reserves" instead of "inferred" reserves. In discussing the resources of all minerals, the Blondel-Lasky classification and terminology is satisfactory to professional engineers and geologists and it is useful to mineral economists.

However, when this classification is applied to the iron ore resources of the world, the summary data for major mining regions or whole countries is not in a form readily usable for appraisals of the existing iron-ore based industries or for assessment of present and future competitive positions. That is, the data so cataloged must be evaluated before it can be used properly.

Most of the existing classifications could be adapted to a realistic evaluation of the world's iron ore resources but the resulting data would require a long list of qualifications and exceptions. Therefore, a new and more useful classification specifically for iron-bearing materials has been devised for this materials survey. Iron-bearing materials that are considered of economic significance are listed in three categories, A, B, and C, based on knowledge of the physical and chemical characteristics, genetics, geology, geographic location, and economic environment. This concept is valid as long as current economic and technical factors prevail and is practical for those who must deal with the complexities of iron resources to quickly determine their relative value. It introduces a better method for comparing iron ore resources on an international basis.

World iron-bearing materials of economic significance are divided into three classes: (1) Class A, (2) Class B, and (3) Class C. These are defined as follows:

Class A

Class A resources are those of the same grade and characteristics as ores presently being mined from similar economic and physical environments to produce premium-quality material. There is every reason to believe that the prime resources will be exploited as they are needed, and there is no apparent reason why they can not be mined profitably at present and in the foreseeable future. Magnetic taconite ore in the Lake Superior district of the United States is a good example of a prime resource. These ores are mined profitably at present, and as long as the relative prices do not change they will continue to be mined profitably. The high-grade iron ore pellet produced from taconite is premium material, and there is no present indication that other forms of iron ore

will supplant it. Among the high-grade ores, those of Western Australia, India, Brazil, Peru, Chile, and part of those in Venezuela, and the Soviet Union meet the criteria for prime resources. It is significant that by far the largest part of the world's prime iron ore resources are low-grade ores that easily can be beneficiated to a high-grade product.

Class B

Class B resources are those of the same grade and characteristics as ores presently being mined from similar physical and economic environments whose end-product quality is below that demanded by most consumers and for which there is no known method of economical upgrading. The future of mediocre resources is, in the long term, doubtful, because at present prices there is reasonable expectation that they will gradually be-supplanted by the prime resources. The soft ores of the Lake Superior district in the United States, part of the soft ores of Canada, Venezuela, Malaysia, and the Philippines, and the high-phosphorus ores of Canada are in this category. Ores classified as mediocre resources in all probability would not be exploited by a new enterprise under the economic conditions existing today. They are mined at present because the investment in the mining equipment needed to do so was made before the market changed to put them in the mediocre category.

Class C

Class C resources are (1) ores of the grade that presently can be mined only with government or other subsidies, (2) ores that have been supplanted by the prime ores, or (3) ores in localities where for one reason or another it is unlikely that the facilities will be installed to exploit them. The minette ores of Great Britain, France, West Germany, Poland, Czechoslovakia, and Yugoslavia are in the marginal resource category because governments or steel companies are subsidizing the mining operation. The Clinton ores of the United States have been supplanted by taconite and high-grade imports. Most of the ores in the Minas Gerais district of Brazil which contain less than 60 percent iron ore are in the marginal category because they will not be exploited until several billion tons of high-grade ore near transportation facilities is exhausted. High-grade ores in the Ungava Bay district of Canada are in the marginal category because they are remote from transportation facilities and the accessibility of easily concentrated taconite ores make it unlikely that the Canadians will go further afield to obtain iron ore.

Summary

Summations of the iron ore resources of the United States by types of ore deposit, by types of mineral and in accord with the Blondel-Lasky classification as compiled by Klemic (*3*) are given in Tables 2 and 3, respectively.

Klemic, as one of the panel experts described below, compiled these data from his own field work and from publications of the Bureau of Mines, Geological Survey, and others. The data are considered comprehensive and authoritive. It should be noted however that the data in tables 3 and 4 are not directly comparable with those in table 8 because of the time limitation on the data in table 8. Some prime ore listed in table 8 is acknowledged only by footnote in Klemic's work.

A summation of the iron ore resources of the world, a summation by types of ore deposit in accord with the Blondel-Laskey classification, and a summation by types of mineral, as compiled by an ad hoc panel of experts for the United Nations, is given in tables 4, 5, and 6, respectively. (*5* pp. 9-11).

The world's iron ore resources by types in accord with the classification devised for this survey are given in table 7 and shown in figure 1. Resource figures given in table 4 differ from the

Table 4.—World iron ore resources

(Million long tons)

Region	Reserves	Potential ore	Total resources
Africa	6,693	24,113	30,806
Middle East, Asia, and the Far East	17,027	53,344	70,371
Australia, New Zealand, and New Caledonia	16,535	Vast	16,535
Canada and West Indies	35,727	87,988	123,715
Europe	20,964	12,598	33,561
South America	33,561	57,478	91,039
U.S.S.R.	108,755	190,739	299,494
United States of America, Puerto Rico, Mexico, and Central America	8,070	96,550	104,620
Total	247,332	522,810	770,141

Table 5.—Iron ore resources of the world: Summation by type of ore deposit

(Million long tons)

Resources	Africa	Middle East, Asia, and the Far East	Australia, New Zealand, and New Caledonia	Canada and the West Indies	Europe	South America	U.S.S.R.	United States of America, Puerto Rico, Mexico, and Central America	Totals	
									Quantity	Percentage
Bedded:										
Lake Superior	19,192	30,904	8,759	62,103	2,953	81,886	132,277	78,343	416,417	54
Minette	6,299	787	---	1,476	19,881	689	104,424	---	133,556	17
Algoma	---	---	787	42,419	---	---	886	591	44,683	6
Clinton	---	---	295	2,067	---	---	3,543	2,756	8,661	1
Iron sands, alluvial, etc.	---	4,232	---	2,461	197	295	---	295	7,480	1
Other and not classified	492	6,693	591	---	2,953	---	492	591	11,812	2
Subtotal	25,983	42,616	10,432	110,526	25,984	82,870	241,622	82,576	622,609	81
Massive:										
Magnitnaya	98	2,657	---	591	492	2,362	11,220	787	18,207	2
Taberg	2,559	787	---	6,889	98	---	32,282	11,712	54,327	7
Kiruna	---	98	---	---	2,559	295	---	886	3,838	--
Bilbao	295	---	---	---	2,559	---	1,083	---	3,937	--
Other and not classified	197	197	295	---	394	---	2,461	295	3,839	2
Subtotal	3,149	3,739	295	7,480	6,102	2,657	47,046	13,680	84,148	11
Residual:										
Laterite	1,279	3,248	98	5,512	295	2,953	---	1,181	14,566	2
Other and not classified	197	98	5,708	197	---	1,968	98	2,362	10,628	1
Subtotal	1,476	3,346	5,806	5,709	295	4,921	98	3,543	25,194	3
Not classified	197	20,668	---	---	1,181	591	10,728	4,823	38,188	5
Total	30,805	70,369	16,533	123,715	33,562	91,039	299,494	104,622	770,139	100

Table 6.—Iron ore resources of the world: Summation by type of mineral

(Million long tons)

Type of mineral [1]	Africa	Middle East, Asia, and the Far East	Australia, New Zealand, and New Caledonia	Canada and the West Indies	Europe	South America	U.S.S.R.	United States of America, Puerto Rico, Mexico, and Central America	Totals	
									Quantity	Percentage
Reserves:										
Hematite	2,362	8,179	1,604	1,988	453	31,750	20,550	394	67,280	27
Magnetite	374	2,628	650	8,031	3,051	246	21,308	778	37,056	15
Goethite	256	650	5,856	---	778	295	13,680	728	22,243	9
Siderite	10	---	---	---	1,653	---	1,181	---	2,844	1
Hematite-magnetite	591	4,144	39	20,570	1,260	394	28,955	3,179	59,132	24
Hematite-goethite	128	315	7,824	4,252	138	915	---	2,234	15,806	6
Hematite-siderite	167	30	315	---	669	---	9,173	---	10,354	4
Goethite-siderite	20	502	---	---	4,764	---	443	335	6,064	2
Goethite-chamosite	---	---	---	---	3,002	---	---	---	3,002	1
Hematite-magnetite-goethite	1,230	108	118	---	98	---	---	266	1,820	1
Hematite-magnetite-siderite	423	---	---	---	2,087	---	---	---	2,510	1
Goethite-siderite-chamosite	---	443	---	---	1,033	---	---	---	1,476	1
Other	1,112	---	148	866	2,018	---	---	177	4,321	2
Not classified	39	89	---	---	10	---	13,474	---	13,612	6
Total	6,712	17,088	16,554	35,707	21,014	33,600	108,764	8,091	247,517	100
Potential ore:										
Hematite	14,418	10,944	---	10,049	315	51,769	8,021	3,110	98,626	19
Magnetite	2,303	5,000	---	23,867	20	531	16,417	11,988	60,126	11
Goethite	1,024	2,510	---	---	463	1,624	91,009	157	96,787	19
Hematite-magnetite	3,592	8,484	---	34,427	1,201	2,175	6,722	61,345	117,946	23
Hematite-goethite	1,211	246	---	3,986	689	1,358	---	3,809	11,299	2
Goethite-siderite	69	2,008	---	---	4,547	---	79	---	6,703	1
Hematite-magnetite-siderite	984	---	---	5,905	118	---	295	10,088	17,390	3
Other	472	305	---	8,277	4,114	10	59	6,023	19,260	4
Not classified	---	23,857	---	1,476	1,083	---	68,156	---	94,572	18
Total	24,073	53,354	Vast	87,987	12,550	57,467	190,758	96,520	522,709	100

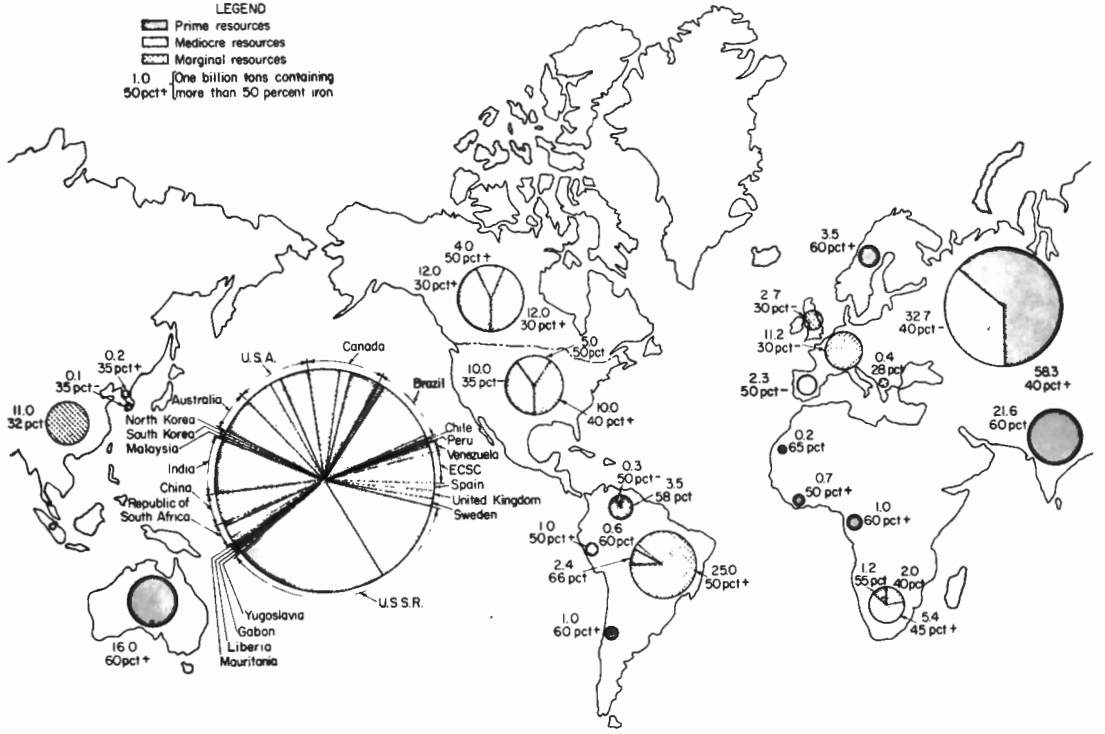

FIGURE 1.—World's principal iron resources.

Table 7.—Principal iron ore resources of the world, significant 1969-2000

(billion tons)

Country	Prime ore		Mediocre ore		Marginal ore	
	Quantity	Grade, percent	Quantity	Grade, percent	Quantity	Grade, percent
North America:						
Canada	12.0	30+	4.0	50+	12.0	30+
United States	10.0	28+	5.0	50	10.0	40+
South America:						
Brazil	2.4	66	.6	60	25.0	50+
Chile	1.0	60+	--	--	--	--
Peru	1.0	50+	--	--	--	--
Venezuela	3.5	58	--	--	.3	50—
Europe:						
E.C.S.C.	--	--	--	--	11.2	30—
United Kingdom	--	--	--	--	2.7	30—
Spain	--	--	2.3	50—	--	--
Sweden	3.5	60+	--	--	--	--
U.S.S.R.	58.3	40+	32.7	40—	--	--
Yugoslavia	--	--	--	--	.4	28
Africa:						
Gabon	1.0	60+	--	--	--	--
Liberia	.7	50+	--	--	--	--
Mauritania	.2	65	--	--	--	--
Republic of South Africa	1.2	55	5.4	45	2.0	40
Asia:						
China	--	--	--	--	11.0	32
India	21.6	60	--	--	--	--
South Korea	--	--	--	--	.1	35
North Korea	--	--	.2	35+	--	--
Malaysia	--	--	.1	50	--	--
Australia	16.0	60+	--	--	--	--
Total	132.4		50.3		74.7	

resources considered significant in table 7. The difference is due to methods of evaluation and variation in cutoff points for ore in some countries. Where differences appear significant the large quantities involved make the situation academic in a realistic time frame. Iron ores discovered since the U.N. survey of 1968 have not been considered in this report.

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CHAPTER 4.—TECHNOLOGY

PROSPECTING

Modern day iron ore prospectors look for multimillion-ton deposits that can be economically mined and beneficiated to a high-grade product. Small deposits, even if high in grade, are of little value except in exceptional circumstances. Iron minerals occur so abundantly that the chief problem for the prospector is to differentiate between an economic and an uneconomic deposit. On the other hand, the presence of iron minerals could lead to unwarranted expenditure for exploration and development on properties in economic environments that preclude profitable exploitation. Iron mineral deposits must be evaluated in relation to the cost of delivering the salable ore to market. Thus, an iron ore prospector should be well versed in geology, mining, metallurgy, and economics.

The iron ore prospector is at an advantage since he is seeking a large target with physical properties that are unusually susceptible to disclosure by geophysical methods. An ordinary magnetic compass will signal the presence of a shallow magnetite ore body by its deviation from magnetic north, and a simple dip needle will indicate the horizontal extent. Many of the iron-ore deposits of the Lake Superior district and of New York and New Jersey were found with compasses and dip needles. However if a deposit is far underground, more sophisticated equipment is needed to find both the non-magnetic and the magnetic iron ore.

Gravitational prospecting methods can be used to search for and estimate the extent of hematite, magnetite, and limonite iron ore deposits, but they are not as satisfactory as electromagnetic methods. Airborne fluxgate magnetometers are now generally accepted as the best of the geophysical iron ore prospecting tools.

The most successful prospectors combine geologic mapping and interpretation with geophysical data from airborne equipment. The data are refined by ground geophysical surveys, and the precise position and extent of a hidden iron ore body are determined by penetrating it. This is usually done with a diamond core drill, but percussion or churn drills can be used for holes within their depth capability.

After the first two or three holes are put in an ore body, prospecting is finished and exploration is begun. There is no precise dividing line between the two. The purpose of prospecting is to find ore, and that of exploration is to determine its quantity and quality.

EXPLORATION

Once an iron mineral deposit of possible commercial interest has been found, the method used to prove enough ore to justify development is determined largely by cost and by the extent to which the risk must be minimized. One is balanced against the other. For taconite and other types of low-grade deposits that require large investment in the benefication plant, the risk of not having enough ore, or of the quality not being properly anticipated, must be practically zero. Normally a supply sufficient for at least a 20-year operation is sought. Fortunately, since the mineral content in most iron deposits does not vary by more than four or five percentage points of recoverable iron, closely spaced sampling rarely is required. Deposits near the surface are explored by drilling and trenching; those with thick overburden are explored by drilling and tunneling. Samples are usually taken at 5 to 10-ft intervals along the tunnel, trench, or drillhole. Careful mapping and close observation of the geologic features, combined with statistical studies, serve to direct the work and to assure having all the necessary information, while keeping expensive physical exploration to a minimum.

Samples are analyzed for iron, manganese, silica, alumina, phosphorus, moisture, and ignition loss. If the mode of occurrence warrants, they are analyzed for magnetic iron and total recoverable iron. A few samples always are anlyzed completely, and if valuable minerals other than iron are present or suspect, all are completely analyzed. Density of ore in place is measured accurately and bulk samples ranging from a few tons to many thousands of tons are taken for metallurgical testing.

Exploration engineers investigate plant sites, transportaiton, waste disposal, and power and water supply. If the property is remote from existing communities, they investigate townsites,

housing requirements, domestic water supply, sewage disposal, and the need or availability of power and heat.

DEVELOPMENT

Since exporation delineates an ore body sufficiently to estimate costs, the approximate mining method has been selected prior to the time it is finally decided to exploit the deposit. But before mining starts, certain preliminary steps are necessary. Collectively they are called mine development. Development is simply preparation for mining. There is no sharp distinction between development and exploration, and in most operating mines the two are carried on simultaneously. Accountants favor classifying the work as development, an expense item, rather than exploration or mine plant, the cost of which is charged to a capital account. Main shafts and haulage ways are considered a part of the mine plant and their cost is amortized over the life of the property.

If an iron ore deposit is to be mined underground, shafts and adits need to be located in stable ground that will not be affected when the ore is extracted. Normally this means that detailed geologic mapping and drilling must extend beyond the known limits of the ore body. A pilot drillhole at shaft sites is usual practice. Adits, shafts, drifts, cross cuts, raises, and inclines through which the ore is moved (and which later are abandoned), are considered development openings. In a new mine, development headings which will open enough ore to produce at planned capacity are driven as rapidly as possible. Thereafter the development openings are made about a year ahead of mining. Most mine operators try to follow the traditional rule of a ton of ore developed for every ton mined.

MINING

Underground Mining

In the last decade practically all the underground iron ore mines in the United States have been highly mechanized, as the operators have been caught between the demand for high-grade ore and rising labor costs. The squeeze has closed the underground mines in the Birmingham district and most of those in the Lake Superior district. The surviving operators are mining high-grade ore bodies, or massive ore bodies where large output and automated operation keeps the mining cost low.

Roofbolting is common, but a combination of bolts, wire net, and gunite commonly is used in large permanent openings. In many of the mines, concrete has replaced lagged timber sets in haulage ways, scam drifts, and crosscuts, and yieldable steel arches have replaced timber for support in heavy, unstable ground.

The simplest underground iron ore mines are in flat-lying, bedded deposits where the beds are not more than 20 ft thick. The ore is extracted by room-and-pillar mining practically identical to the method used in mining coal. Iron deposits in the Lincolnshire and Rutland districts of England, and in the Lorraine district of France and Luxembourg are mined by this method. By robbing the pillars to the point of failure, approximately 80-percent extraction is achieved in room-and-pillar iron ore mining.

Room-and-pillar methods are more flexible in iron mines than in coal mines because ventilation requirements are not as stringent. However, the same methodical development is preferred because it makes for easier control of the ground. The large areal extent opened makes transportation and maintenance of haulage ways just as expensive as in a coal mine. If the deposit is worked from outcrops or is near the surface, common practice is to develop it with two or more inclines, one of which is used exclusively for a haulageway. In many of the newer mines, the ore is moved on a conveyor belt; in the older mines it is moved by rail or in skips on inclines. Either way, large-capacity equipment is the rule.

The minette iron ores of Europe are drilled with electric or air-powered augers, either hand-held or mounted on columns, or mounted on flexible-arm, mobile jumbos. Harder ores in room-and-pillar mines are drilled with air-powered percussion drills. Trackless equipment is common at the working faces. The gamut of coal mining equpment is used from continuous miners to electric power-cable, low-clearance shuttle cars. However, coal mining equipment is greatly strengthened for use in an iron mine.

Massive- and vein-type iron ore deposits are mined principally by caving methods, supplemented by shrinkage and sublevel stoping. Sublevel caving, as developed in the Lake Superior mines, apparently is still the preferred method in ore bodies where dilution is a problem. The mining method is selected to fit the ore body, and there are about as many variations of each method as there are mines that use them. Preference for vertical shafts and large openings are practically the only common mining elements. Percussion drills and carbide insert bits predominate (fig. 2). Typical heavy-duty mining and transportation

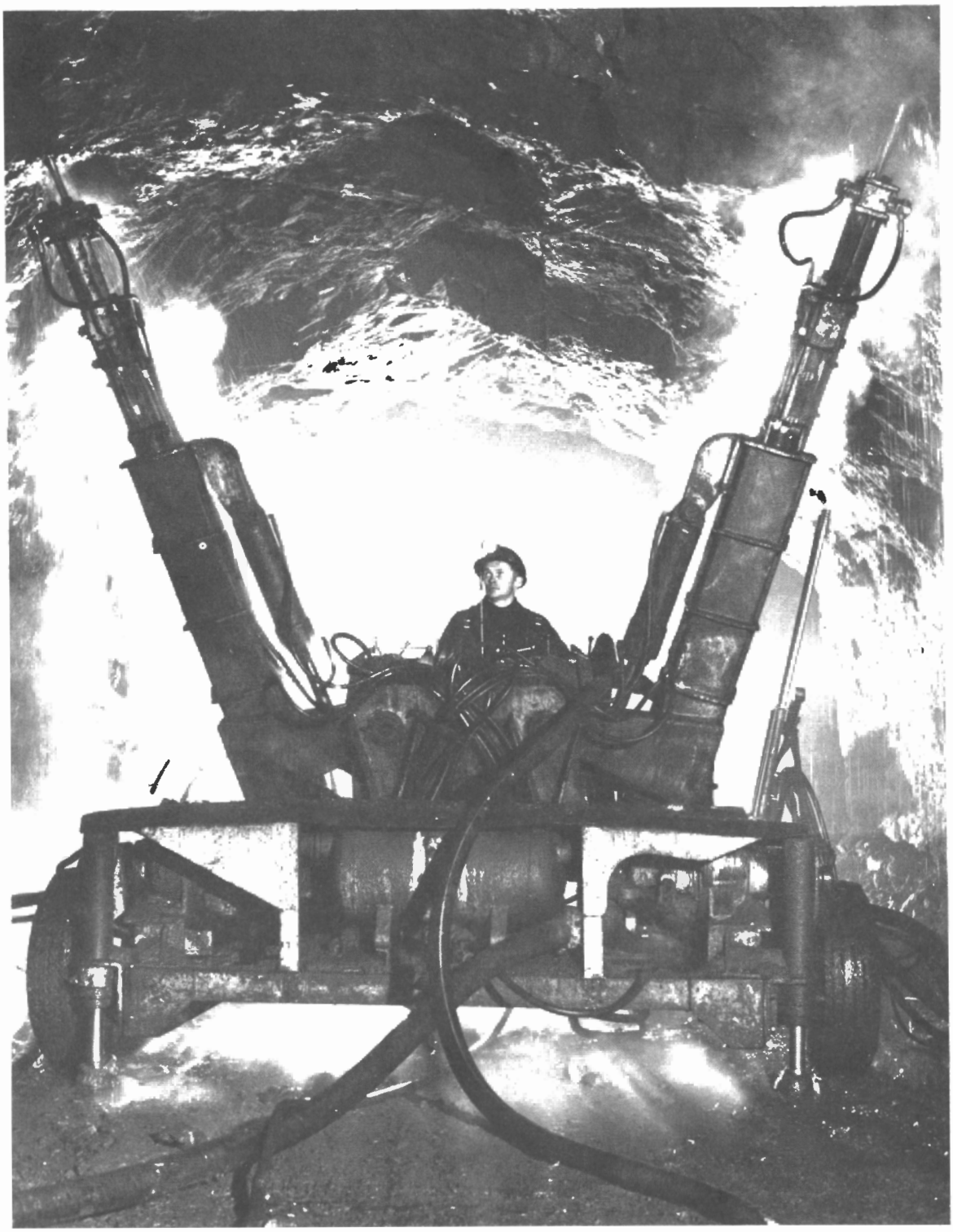


FIGURE 2.—Percussion drilling equipment underground in Sweden.

equipment is used, in contrast to the coal equipment used in the bedded deposits; scrapers and combination load-haul-dumps are the preferred methods of handling.

Open Pit Mining

Open pit mining is the most attractive method of exploiting iron ore deposits because it permits large variation in the rate of output and in most instances it is the least expensive. Its use is limited by the depth and nature of the overburden and the cost of removing it. The economical stripping ratio (the ratio of overburden to ore) is about 2 to 1 in most districts, but some of the brown iron ore deposits of the Southern United States are mined profitably with stripping ratios as high as 5 to 1.

Where the overburden must be blasted, rotary, churn, and wagon drills are used for the blastholes; the principal explosive used is a mixture of amonium nitrate and fuel oil. Some form of millisecond-delay detonation is used, unless the blasting is done merely to loosen a tight rock formation.

Dragline excavators, ranging in size from a 2-cu yd bucket on a 100-ft boom to a 25-cu yd bucket on a 320-ft boom, are the principle means of digging unconsolidated overburden where the spoil (or waste) can be cast. Power shovels with dippers ranging in size up to 14 cu yds are used in hard material and for loading overburden which must be transported to remote spoil banks. However, where overburden and ore have similar physical characteristics, draglines and shovels are used interchangeably. Tractor-drawn scrapers, bulldozers, and self-powered loaders are utilized where the character of material and the length of haul make their use profitable. Off-highway trucks are probably used more than any other single piece of equipment to transport overburden to spoil dumps, but truck-conveyor belt combinations are used widely if the haul is a mile or more (fig 3).

Spoil is piled adjacent to the mining pits in flat-lying deposits where the pits are to be backfilled as mining progresses. It is placed in low areas remote from the deep pits in massive deposits. Topsoil is removed separately and stored apart from the spoil where the surface is to be restored. With this procedure, only careful observation discloses the difference between a mined and unmined area 10 years after mining. Agricultural lands usually are returned to full use within 5 years.

For iron ore other than hard, massive taconite, the ore is drilled with the same types of equipment as is the overburden. Except in taconite mining, which will be discussed separately, churn drills predominate; rotary and down-the-hole percussion drills are used more than conventional wagon drills and jackhammers. Each has its place, but economics usually favor the large units. Blasting agents and detonators are the same as used in the overburden.

Loading shovels range from 1- to 8-yd dippers, with 4-yd dippers the practical standard because they provide flexibility and adequate capacity in most of the mines. Mining benches range from 25 to 35 ft high (fig 4). Grades determine the choice of haulage equipment. Rail is the least expensive in ideal pits when the ore is moved to market in the same cars. However, the geometry of iron ore bodies, the depth of the mines, and the need to beneficiate the ore usually favor a combination of load and transfer conveyors, trucks and conveyor, trucks and skip, or any of these combinations used with rail. The trend has been that trucks and conveyors are relacing rail haulage.

Open Pit Taconite Mines

Open-pit taconite mines differ from conventional iron ore mines only in the character of the ore and the relative size of operation. Since the taconite is silceous, the ore invariably is lower grade and harder than that in the conventional deposits. Fuel oil-oxygen jet-piercing equipment was developed specifically to penetrate the taconite, and has been the principal means of doing so. However, large rotary drills are preferred in some areas.

Down-the-hole percussion drills, three-cone-bit rotary drills, and churn drills are used in low-grade deposits that are loosely classified as taconite, in which the ore is softer and the minerals are more coarsely grained than in the classic Minnesota taconites (fig 5).

Taconite mining benches tend to be higher than those of conventional mines. The average is about 35 ft. Drillhole spacing and blasting are more carefully controlled because good fragmentation in the mine lowers crushing costs at the mill.

Loading shovels in the taconite mines range in capacity from 5 to 14 cu yds. The ore is transported in 75- to 90-ton standard-gauge railroad cars, and in off-highway trucks and trailers with capacities of 100 tons or more. Conveyor belts are not used to transport taconite ore until after it has been crushed and sized (fig 6).

Quality control is an integral part of all forms of iron ore mining. Detailed records of sampling are kept, starting with exploration, so that when the ore is delivered to the mill or loaded for

FIGURE 3.—Open pit iron ore mine, Peru.

market its characteristics and iron content are well known. Conventional ores are blended to provide a uniform mixture for market. Taconite mining is planned from sampling records to obtain a constant flow of rock with uniform mineralogy, grade, and hardness.

BENEFICIATION

Present day market specifications are so stringent that practically all iron ore must be beneficiated before it can be sold. Even the very high-grade ore is carefully sized and graded. The minimum treatment for blast furnace feed is to crush to minus 4 in and screen out the minus ¼ in. Maximum beneficiation involves crushing and grinding to liberate the individual mineral crystals, concentrating, and then agglomerating to a specified size.

Iron ore crushers range in size from 18-in jaw, used occasionally at some iron ore mines, to 60-in gyratories and 7-ft cone crushers, used for the taconite-type ores (fig 7). The ore to be concentrated is ground in conventional ball-and-rod mills ranging in size up to 14.0 ft in diameter, and in autogenous mills ranging in size up to 32 ft in diameter (fig 8).

Practically all the known methods of concentrating minerals are used in beneficiating iron ore. The process used depends on the characteristics of the ore; therefore, iron ore beneficiation processes are categorized by those used to treat (1) brown ores containing limonite or goethite, (2) oxidized ore containing hematite, martite, goethite or limonite, (3) magnetite taconite, (4) specularite-jaspilite, and (5) complex magnetite ores containing hematite, martite, and other iron minerals.

Brown iron ores are beneficiated in simple, often portable washing plants. The most elementary of these consists of a grizzly feeding directly into a log washer, followed by a picking belt that transports the concentrate to railroad cars or trucks, or to storage. Oversize is either rejected or broken with a sledge hammer. The log-washer overflow

(Courtesy of American Iron Ore Association).

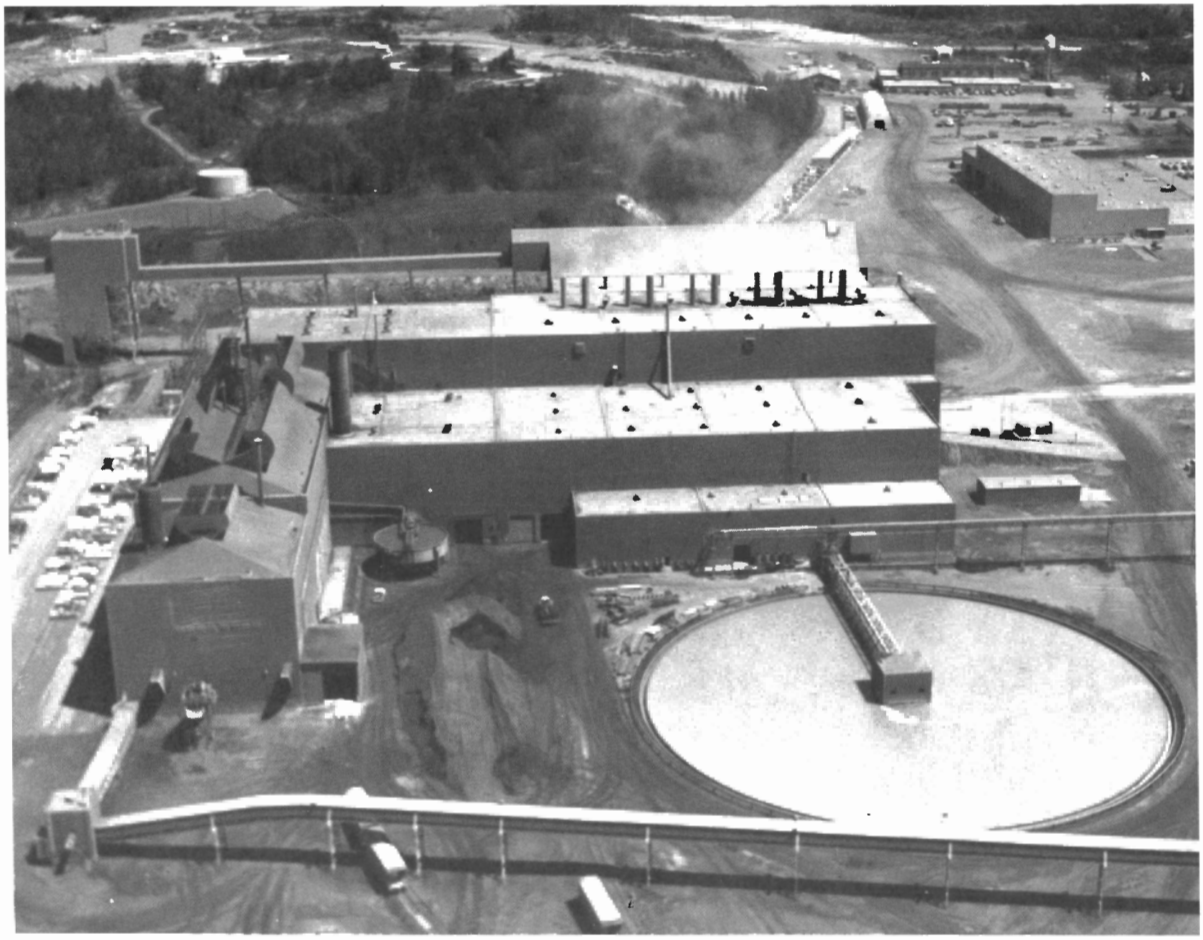
FIGURE 4.—Open pit iron mine, Canada.

goes by gravity to a tailing pond where the water is reclaimed.

Where clay, silica, and earthy materials adhere to the iron minerals and where a large part of the iron minerals are oversize lumps, the washing plants are more complicated. For these ores, a typical plant consists of a feed mechanism that conveys lumps to a trommel in which a water spray breaks up some of the clayey material. The minus ¼-in material is rejected to holding ponds where it remains as fill or is beneficiated after settling. The minus 4-in material passes to a rotary scrubber, then to a washer or to a screw-type classifier followed by a picking belt, where it becomes a finished concentrate. Plus 4-in material is crushed to minus 3 in, screened to reject minus 2 in and then passed to a washer. The minus 2-in material goes to a secondary scrubber and then is dewatered in a screw-type classifier to produce a finished concentrate.

(Courtesy of the Hughes Tool Co.).

FIGURE 5.—Three-cone, tungsten carbide hand-laced rock bit for rotary drill.



(Courtesy of The Hanna Mining Co.)

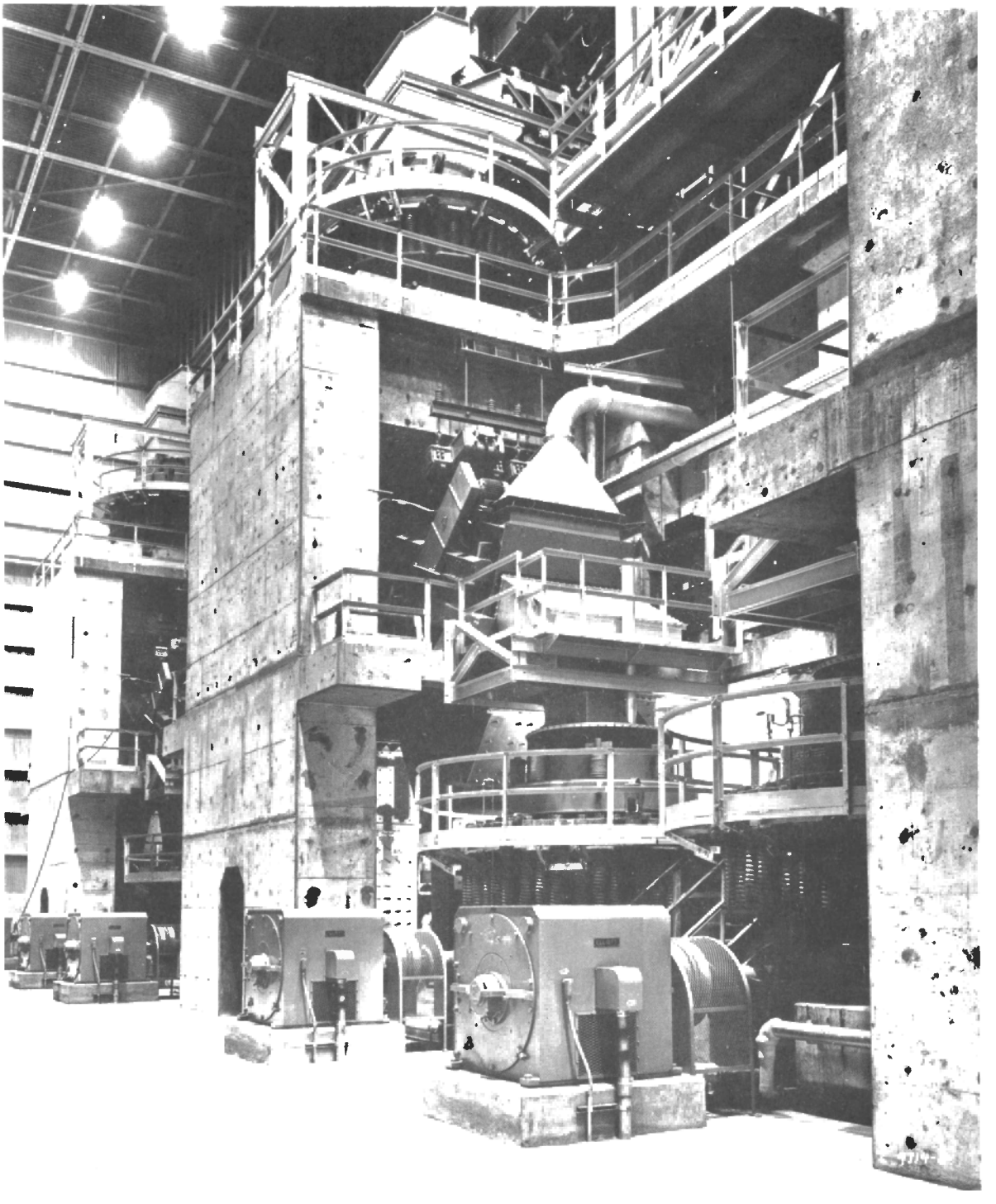
FIGURE 6.—Butler Taconite Plant, Cooley, Minn.

Brown iron ores have been concentrated in heavy media plants using ferrosilicon as the media. Both cone and drum separators are used.

The oxidized ores are typified by the lean ores of the Lake Superior district. These ores are alteration products of iron formation, from which the silica and other impurities have been partly removed by oxidation and leaching. Increasingly complex beneficiation processes have been developed to treat these ores coincident with the type of deposit being mined. Thus the benficiation process development has been chronological. Since no one of the types of ore mined in the Lake Superior district has yet been completely depleted, none of the beneficiating processes developed to treat each type of ore has yet been completely outmoded. The wide variety of beneficiating plants still treating oxidized ores is shown in table 8.

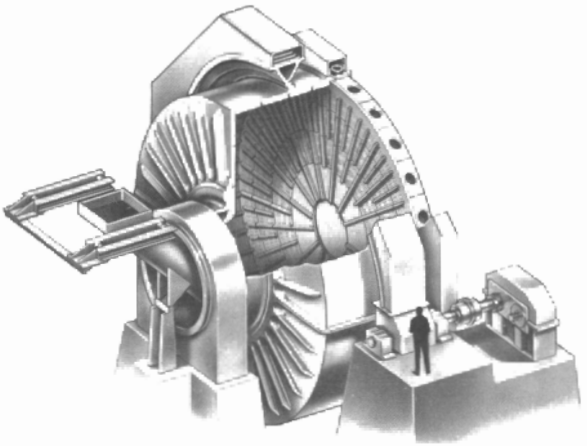
Oxidized ores can be roughly classified as (1) mixtures of iron minerals with clay, sand, and silt, (2) these mixtures cemented together, and (3) iron minerals and gangue minerals with clay and silt. The simple mixtures are treated in washing plants much the same as those used to treat the brown ores. If the impurities are sandy, the mixtures are screened and classified. The cemented mixtures are crushed prior to washing, and bowl classifiers are commonly used to separate ore minerals from the fine gangue. Iron oxides mixed with gangue minerals are separated after crushing by gravity concentration using jigs, spirals, heavy media, or heavy-media cyclone separators. Fine-grained waste from the heavy-media plants has been processed by flotation to recover the iron minerals.

Beneficiating magnetite taconite is theoretically easy, but practically difficult because fine grain size and pulp density must be controlled economically



(Courtesy of Rexnord, Norberg Machinery Group).

FIGURE 7.—Symons 7-foot standard cone crushers.



(Courtesy of Rexnord, Norberg Machinery Group).

FIGURE 8.—Cutaway view of autogenous mill.

to achieve good recovery with satisfactory grade. The ore passes through a coarse-crushing plant, a fine-crushing plant, rod-and-ball mills, magnetic cleaners, and magnetic finishers (fig. 9). All the taconite plants have multi-identical circuits operating in parallel. The crushing departments probably are the most important part. Ore is crushed in three or four stages and all plants are provided with interchangeable units beyond the first stage. Most taconite plants have some sort of elutriation device to wash fine silica out of magnetic concentrates. At some plants the magnetic concentrates are upgraded by flotation.

In all existing magnetite taconite plants but one, the ore is ground first in rod mills and finished in ball mills. Closed circuits with cyclone classifiers provide multistage grinding. Control of the cyclone feed density has proved critical in maintaining constant sizing from the closed-circuit system (*18*). Wet electromagnetic or permanent magnetic separators reject a large part of the gangue in rougher separation stages. About 40 percent of the feed can be rejected in final tailing in a cobbing circuit and an additional 12 to 15 percent can be rejected in a roughing circuit. The more gangue rejected in cobbing and roughing, the higher the grade of the final concentrate (*19*). The final concentrate contains 63 to 68 percent iron. Its grain size ranges from 85 percent minus 325 mesh to 95 percent minus 500 mesh (fig 10).

Fine-grained specularite in hard, siliceous-banded rocks, termed jaspilite, is the only type of iron ore that at present is beneficiated principally by flotation. This ore is concentrated by the Republic plant on the upper peninsula of Michigan. The ore is crushed in three stages, and rough ground in a rod mill open-circuited to a hydroscillator classifier which is in closed circuit with a fine-grinding ball mill. Overflow from the hydroscillator is fed to two desliming cyclones, underflow from the cyclones goes to conditioners, and the overflow, approximately minus 20-micron grain size, goes to waste. The ground ore is concentrated by flotation in three stages—rougher cells, cleaner cells, and recleaner cells. The concentrate contains 61.7 percent iron with 40 to 45 percent minus 325-mesh grain size. The concentrate is reground to at least 80 percent minus 325 mesh, which results in overgrinding, measured by liberation of the ore minerals, but which has been found necessary to produce a product suitable for pelletizing.

The reground concentrate is heated in four stages and refloated (without additional reagents) in three cleaner stages and three scavenger stages to make a final concentrate containing 67 percent iron. Approximately 84 percent of the iron in the primary float circuit is recovered in the final concentrate.

Coarse-grained specularite, hematite, and some magnetite mineral ores are beneficiated by crushing and grinding, to liberate the minerals, and then separating iron minerals from the gangue with gravity concentration equipment. Humphrey[2] spiral separators, jigs, and heavy-media separators are the principal means used in the separation.

Complex magnetite ores containing hematite, martite, and other valuable minerals are crushed in two or three stages in much the same manner as the magnetic taconites. The ores are ground in conventional two-stage rod-and-ball mill circuits, but waste rock is rejected before the ore is ground if the loss of hematite is not excessive. Magnetite is recovered by gravity or magnetic separation of the coarse portion; the fines are treated by flotation to recover massive and specular hematite, hematite-magnetite, pyrite, pyrite chalcopyrite, and apatite.

AGGLOMERATION

All minus ¼-in iron ores and iron mineral concentrates are agglomerated before being smelted. Pelletizing is the principal method of agglomerating at the mines and sintering is the principal method at the steel mills. Ores and concentrates not amenable to pelletizing occasionally are nodulized or briquetted if there is a favorable market for dense agglomerates suitable for open hearth use. However, nodulizing and briquetting have not

[2] Reference to specific brands or makes of equipment does not imply endorsement by the Bureau of Mines.

Table 8.—Benefication plants operating on Minnesota iron ranges, 1970

Name of plant	Company	Location	Type of plant
MESABI RANGE			
Arcturus	U.S. Steel Corp.	Marble	Washing, hi density, spirals, cyclones.
Butler Taconite	Itasca Pellet & Inland Steel	Cooley	Taconite concentration.
Canisteo	The Cleveland-Cliffs Iron Co.	Coleraine	Washing and high density.
Canisteo Fines	The Cleveland-Cliffs Iron Co.	Coleraine	Fines treatment.
Coons-Pacific	Coons-Pacific Co.	Clinton	Crushing, washing, jigging, high density.
Danube	Pickands Mather & Co.	Bovey	Crushing, washing, jigging, high density.
E. W. Davis Works	Reserve Mining Co.	Silver Bay	Taconite concentration.
Fairlane	Eveleth Taconite Co.	Forbes	Taconite concentration.
Gross-Nelson	Rhude & Fryberger, Inc.	Eveleth	Washing, jigging, high density.
Hill Annex	Jones & Laughlin Steel Corp.	Calumet	Crushing, screening, washing, high density, spirals.
Hill-Trumbull	The Mesaba-Cliffs Mining Co.	Marble	Washing and high density.
Hoyt Lakes	Pickands Mather & Co.	Aurora	Taconite concentration.
Hull	Rhude & Fryberger, Inc.	Hibbing	Washing.
Julia	Pittsburgh Pacific Co.	Virginia	Washing and high density.
Lind-Greenway	Jones & Laughlin Steel Corp.	Gr. Rapids	Crushing, screening, washing, jigging, high density.
Mahoning	Pickands Mather & Co.	Hibbing	Crushing, washing, high density.
McKinley	Jones & Laughlin Steel Corp.	Biwabik	Crushing, screening, washing.
Minntac	U.S. Steel Corp.	Mountain Iron	Taconite concentration.
National Steel Pellet	National Steel & Hanna Mining	Keewatin	Taconite concentration.
Pierce	Hanna Ore Mining Co.	Hibbing	Washing, high density, spirals, cyclones, sizing.
Pilotac	U.S. Steel Corp.	Mountain Iron	Taconite concentration.
Plummer	U.S. Steel Corp.	Coleraine	Washing, spirals, cyclones.
Rouchleau	U.S. Steel Corp.	Virginia	Crushing, screening, sizing.
Sherman	U.S. Steel Corp.	Chisholm	Crushing, screening, washing, high density, spirals.
Stephens	U.S. Steel Corp.	Aurora	Crushing, screening, sizing.
Trout Lake	U.S. Steel Corp.	Coleraine	Washing, high density, spirals, cyclones.
West Hill	The Hanna Mining Co.	Coleraine	High density, cyclones.
Whiteside	Snyder Mining Co.	Buhl	Crushing and screening.
CUYUNA RANGE			
Lauretta	National Steel & Hanna Mining	Wolford	Crushing and sizing.
Virginia	Pittsburgh Pacific Co.	Ironton	Washing, jigging, high density, cyclone.

Principal source: University of Minnesota Bulletin, Mining Directory Issue, 1971, pp. 220–221.

proven as satisfactory an agglomeration method as sintering.

Pelletizing

The word pellet, which means little ball, literally describes the product of modern iron mineral pelletizing plants. The pellets approach spherical shape during the balling state and are usually ⅜ in to ½ in in diameter. Their composition varies according to the grade of the ore or concentrates used to make them, but seldom is below 62 percent iron. In the United States the average is about 63 percent. (A typical drum-type balling operation is shown in figure 11.)

The success of pelletizing depends on controlling the physical properties of the raw materials within narrow limits throughout the process, while adjusting processing conditions to compensate for slight variations that invariably show up in mining. Taconite concentrate that is at least 85 percent minus 325 mesh is an ideal raw material for pelletizing. Coarser material does not ball as easily and the resulting pellets in most instances are not as strong nor as durable. Finer concentrate can be pelletized satisfactorily but is somewhat more difficult to handle because of its nature.

Normally pelletizing is a two-stage process. "Green" pellets are formed from fine-grained material mixed with bentonite binder, and in some instances with coke breeze or anthracite coal fines, in balling drums or rotating-disc saucers. Bentonite is the normal binder used at most pelletizing plants. The quantity ranges from 9 lb to 18.5 lb per long ton of concentrate. Then the green pellets are indurated with heat in a traveling grate, grate-kiln, or shaft furnace. Traveling grates are designed with updraft, downdraft, and combination updraft-downdraft blowers.

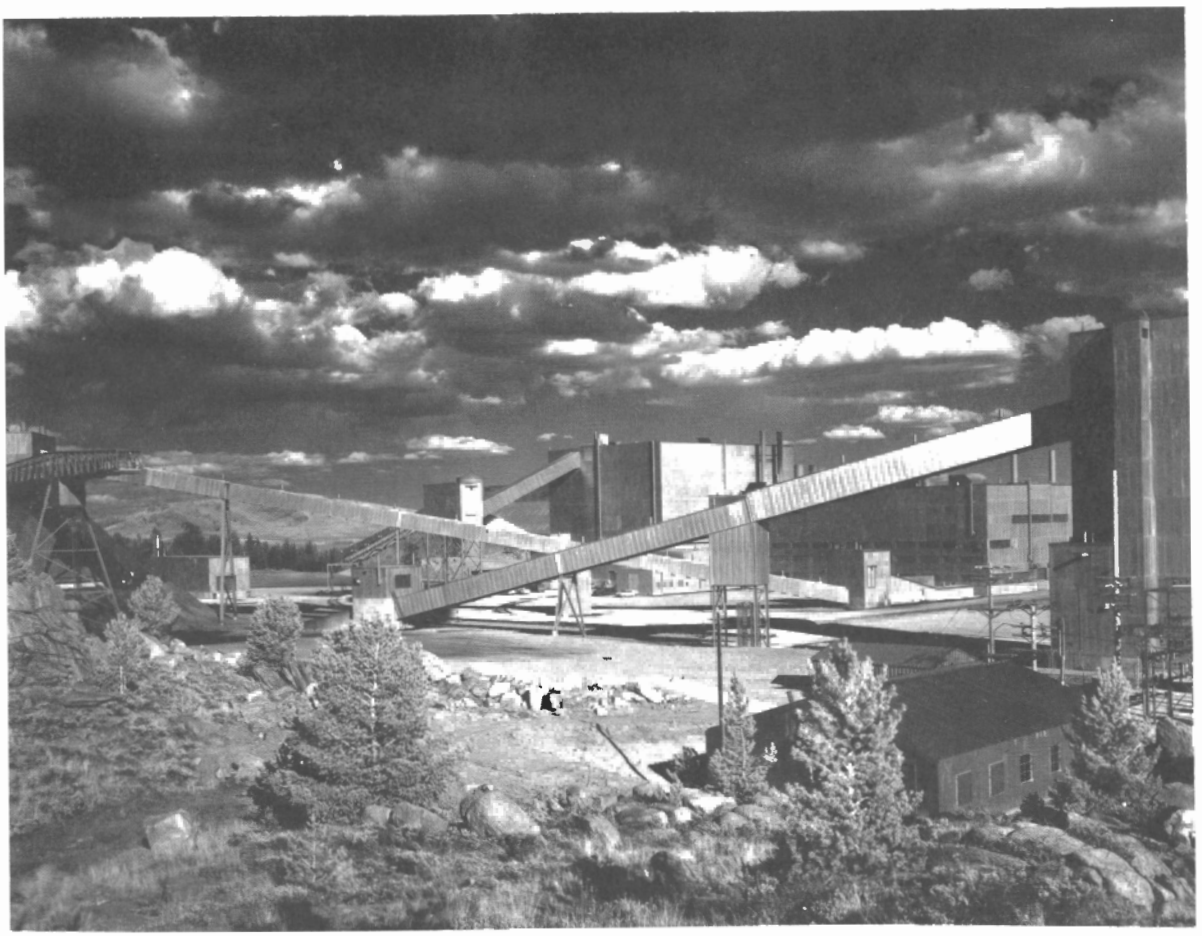


FIGURE 9.—Crushing plant, U.S. Steel Corp., Atlantic City, Wyo., taconite mine.

Indurating green pellets requires a temperature between 2,350° and 2,470° F. The shaft furnace is a little more efficient than others, but all are designed to recuperate the waste heat. Oxidation of magnetite is exothermic, so magnetite ores and concentrates need less heat than hematite. Outside heat requirements range from 500,000 Btu per long ton of magnetite concentrate in a shaft furnace process, to over 1 million Btu per long ton of mixed hematite Btu magnetite concentrate in a grate-kiln process.

Cold-bonded pellets in which cement is used for binder have been developed and tested on a commercial scale in Sweden. The pellets are made by the Grangcold Pellet Process, in which they are formed in a disc-type pelletizer with a mixture of 90 percent iron ore concentrate and 5 to 10 percent portland cement clinker without gypsum. The green pellets are cured by first bedding them for at least 30 hr in iron ore concentrate. This is followed by a 5-day hardening period in bins, then to a final storage area for at least 2 weeks before use.

Both lump ore and pellets may be transported long distances by water. Figures 12 and 13 illustrate two methods of loading ore into carriers—the first by gravity flow, the second by a traveling conveyor system.

Sintering

Sintering does not require as restricted a variety of raw materials as pelletizing, but is nevertheless a process requiring careful blending of the raw materials and skill and precision in working them. The sintering department is usually charged with salvaging the iron-bearing waste of an integrated steel plant. In some instances, however, it may be more profitable to discard low-grade iron-bearing material rather than produce below-standard sin-

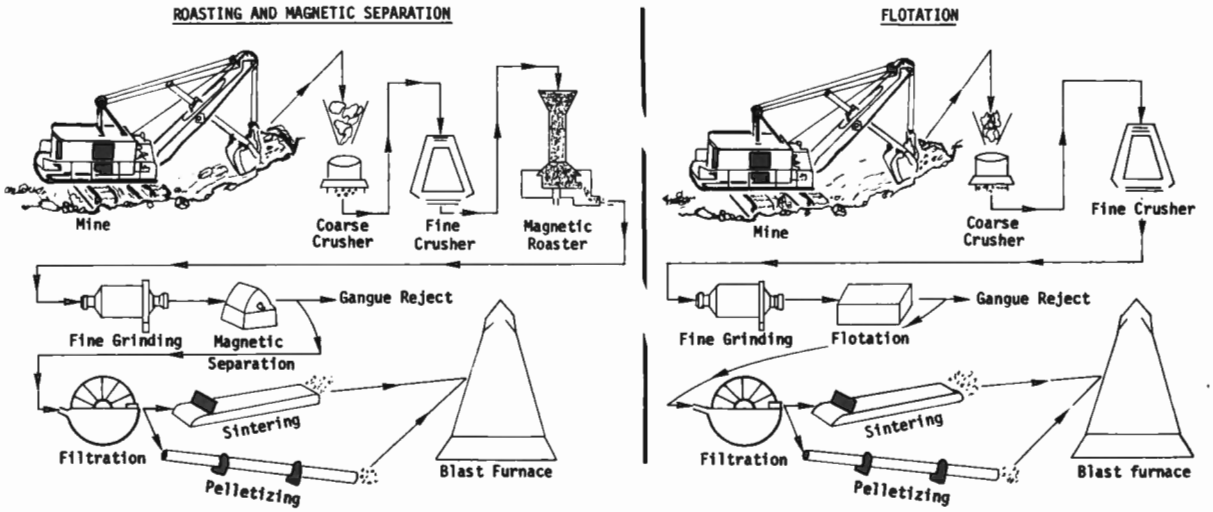


FIGURE 10.—Simplified flowsheet showing methods of beneficiating non-magnetic ores or semi-taconite ore.

ter. Iron ore fines and concentrate are the principal raw materials for sinter; mill scale, flue dust, limestone, dolomite, and coke breeze are the minor materials.

Sinter materials range below minus ¼-in mesh. If much very-fine-grained material is present, it may be pelletized in mixing by controlling the moisture to obtain a balling action. The pellets thus formed usually have less than a 1/16-in diameter. Limestone or dolomite is added to facilitate the sintering action and in some instances enough is added to make the sinter self-fluxing. The amount of fluxing is determined for each operation by considering (1) the cost of handling the flux, (2) the sintering capacity, and (3) the advantages of providing self-fluxing feed for the blast furnace. In the United States most operators make a lime sinter somewhat less than self-fluxing.

Heat for sintering is obtained from carbon in coke breeze or anthracite or bituminous coal. Just enough fuel is added to bring the temperature to the point of incipient fusion (approximately 2,700° F), taking into account the heat from exothermic reactions. Carbon requirement ranges from approximately 4 to 7 wt pct. In some operations a limited amount of heat is provided by oxidation of the contained sulfur and arsenic.

The mix is sintered on a traveling grate or in a stationary-hearth pan furnace. Stationary-hearth furnaces are used at only a few mines and are not used at steel mills in the United States. This is a batch process in which the pans are filled with mix, ignited, sintered, and then dumped.

Traveling grate machines range in size from 6 ft by 30 ft to 13 ft by 184 ft. Wind boxes pull air and the combustion front down through the mix. Special feeders provide a porous, uniform bed. In areas of high-cost fuel, the bed is placed in two layers to take advantage of the heat saved in a partially dried bottom layer, and the heat of combustion is recuperated by bringing the exhaust gases under the hood. Dust control equipment is an integral part of all plants.

Hot sinter is preferably cooled by air and may be screened hot or cold. Fine screenings are returned to the primary circuit. Some operators make a special effort to remove and recycle all fines because sinter fines in the mix facilitate sinter production and make a better product.

Nodulizing

Fine-grained iron ore can be agglomerated in a rotary kiln where the rolling action forms lumps or nodules when the temperature reaches the point of incipient fusion. This process does not require as careful a control of raw materials as does either pelletizing or sintering, but the operation invariably is complicated by oversize balls and by the formation of rings in the kiln. As far as is known, the nodulizing process was not used commercially for iron ore in the United States during

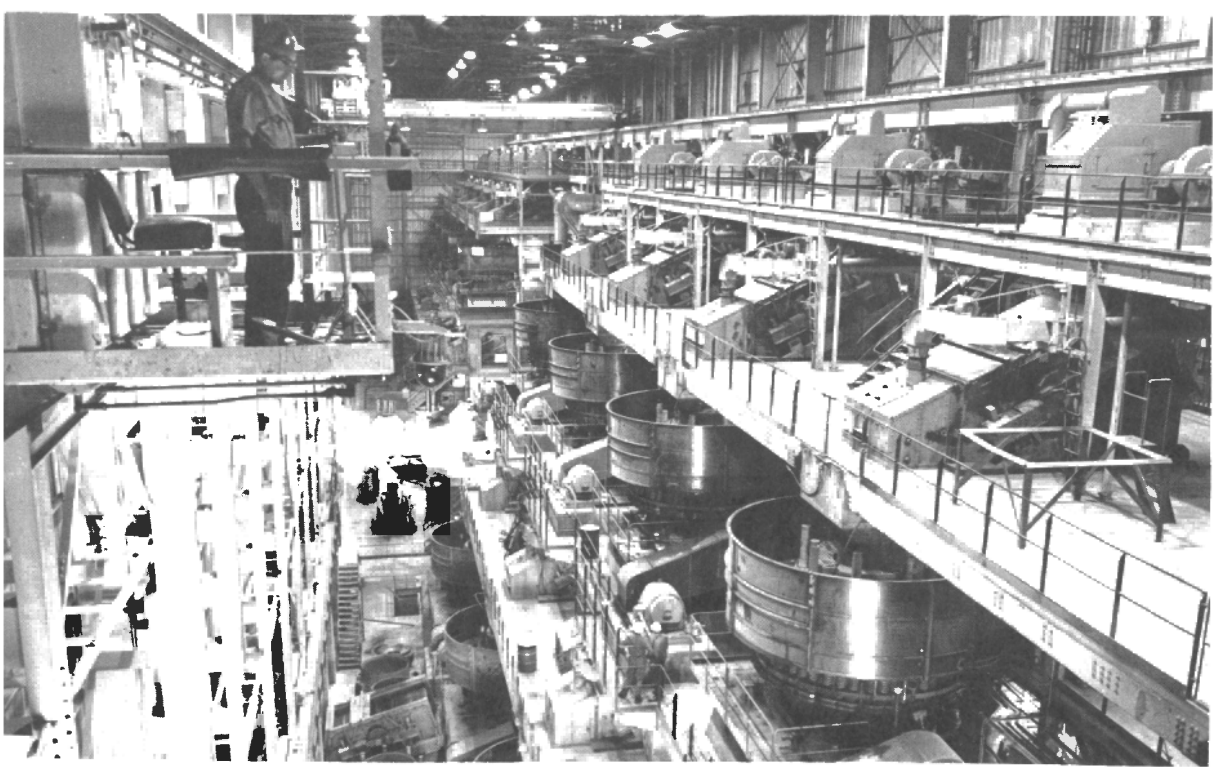
Table 9.—Pelletizing plants of the world as of December 31, 1970

Country, province or state	Company and plant or location	Annual capacity [1] (long tons)
UNITED STATES		
California	Kaiser Steel Corp.—Eagle Mountain	2,200,000
Michigan	Cleveland-Cliffs Iron Co.—Empire	3,400,000
	Cleveland-Cliffs Iron Co.—Humboldt	800,000
	Cleveland Cliffs Iron Co.—Pioneer	1,400,000
	Cleveland Cliffs Iron Co.—Republic	2,500,000
	Hanna Mining Co.—Groveland	2,100,000
Minnesota	Erie Mining Co.—Hoyt Lakes	10,300,000
	Eveleth Taconite Co.—Eveleth	1,800,000
	Hanna Mining Co.—Butler Taconite Project	2,400,000
	Hanna Mining Co.—National Steel Pellet Project	2,400,000
	Reserve Mining Co.—Silver Bay	10,700,000
	U.S. Steel Corp.—Minntac	6,000,000
Missouri	Meramec Mining Co.—Pea Ridge	2,000,000
	Hanna Mining Co.—Pilot Knob	1,000,000
Oregon	Midland-Ross Corp.—Portland	400,000 [2]
Pennsylvania	Bethlehem Mines Corp.—Cornwall	700,000
	Bethlehem Mines Corp.—Grace	1,500,000
Wisconsin	Jackson County Iron Co.—Black River Falls	750,000
Wyoming	U.S. Steel Corp.—Atlantic City	1,500,000
Total		54,250,000
CANADA		
Newfoundland	Carol Pellet Co. (I.O.C.)—Labrador City	10,000,000
Ontario	Caland Ore Co. Ltd.—Atikokan	1,000,000
	Dominion Foundries & Steel Ltd.—Kirkland Lake (Adams)	1,250,000
	Dominion Foundries & Steel Ltd.—Temagami (Sherman)	1,100,000
	International Nickel Co.—Copper Cliff	1,000,000
	Marmoraton Mining Co. Ltd.—Marmora	500,000
	National Steel Corp. of Canada Ltd.—Moose Mountain	700,000
	Steel Co. of Canada, Ltd.—Bruce Lake (Griffith)	1,500,000
	Steep Rock Iron Mines, Ltd.—Steep Rock Lake	1,350,000
Quebec	Wabush Mines—Pointe Noire	6,000,000
	The Hilton Mines—Shawville	900,000
Total		25,600,000
OTHER COUNTRIES		
South America:		
Brazil	Companhia Vale do Rio Doce—Tubarao	2,000,000
Mexico	Hojalata y Lamina, S.A.—Colima	1,100,000
Peru	Marcona Mining Co.—San Nicolas	3,500,000
Western Europe:		
Belgium	Forges de Clabecq S.A.—Clabecq-Brabant	600,000
Finland	Otanmaki Oy.—Otanmaki	300,000
	Outokumpu Oy.—Kokkola	300,000
France	Mines de Fer de Segre—Segre	100,000
Germany	Salzgitter AG—Drutte	250,000
Italy	Montedison S.p.A.—Follonica	650,000
Netherlands	Hoogovens—IJmuiden	3,000,000
Norway	A/S Sydvaranger—Kirkenes	1,200,000
	Norsk Jernverk A/S—Moi Rana	600,000
Sweden	Granges AB—StrassaGrangesberg	2,000,000
	L.K.A.B.—Kiruna	1,600,000
	L.K.A.B.—Malmberget	1,100,000
	L.K.A.B.—Svappavaara	1,800,000
	Sandvikens Jernberk AB—Bodas	55,000
	S.K.F.—Hofors	100,000

Table 9.—Pelletizing plants of the world as of December 31, 1970—Continued

Country, province or state	Company and plant or location	Annual capacity [1] (long tons)
	Stora Kopparberg—Falun	80,000
	Uddeholms AB—Persberg	60,000
Eastern Europe:		
U.S.S.R.	Krivoi Rozhskiy Mining and Beneficiation Combinat—Krivoi Rog	4,000,000
	Sokolovsk-Sarbayski and Beneficiation Combinat—Kazakhstan	6,500,000
	Kachkanarski Mining and Beneficiation Combinat—Kachkanar	700,000
Asia:		
India	Chowgule & Co. Ltd.—Goa	500,000
Japan	Kawasaki Steel Corp.—Chiba	500,000
	Yawata Iron & Steel Co.—Tobata	500,000
	Kobe Steel Works Ltd.—Nadahama	1,000,000
	Kobe Steel Works Ltd.—Kakogawa	2,000,000
People's Republic of China	Kobe Steel Works Ltd.—Paotow, Mongolia	1,100,000
Philippines	Pellet Corp. of the Philippines—Larap	750,000
Oceania:		
Australia	Broken Hill Pty. Co. Ltd.—Whyalla	1,500,000
	Hamersley Iron Pty. Ltd.—Dampier	2,000,000
	Savage River Mines Ltd.—Port Latta	2,250,000
Africa:		
Liberia	Liberian-American Swedish Minerals Co.—Buchanan	2,000,000
	Bong Mining Co.—Bong	2,000,000
Total other countries		51,305,000
World total		131,155,000

[2] Metalized pellets.
[1] Nominal.



(Courtesy of The American Iron Ore Association)

FIGURE 11.—Taconite beneficiation plant, crushing units.

1970, and it may have been proven impractical in all circumstances.

Briquetting

Like nodulizing, briquetting was not used commercially in the United States to agglomerate iron ore in 1970. Briquettes had been a satisfactory substitute for open-hearth lump ore when that ore was in short supply in the late fifties and early sixties. They were made in roll or punch presses from fine ores combined with a binder such as lime, cement, waste sulfite liquor, or molasses. The most successful commercial operation, which was discontinued in 1962, utilized molasses and fine limestone for binder to make 4-in, pillow-shaped briquettes in a roll press.

Orinoco Mining Co. reportedly will produce 1 million tons of metallized-iron briquettes annually by a fluidized-bed, hot-pressing process in Venezuela. The plant was scheduled for completion in 1971.

SMELTING

Iron ore, concentrate, or agglomerate can be smelted to produce iron in several types of equipment, but by far the most widely used is the blast furnace. It is the most efficient device known for reducing iron oxide, measured either by the quantity of heat required per unit of output or by the expenditure of labor per unit.

Heat utilization is the usual measure of blast furnace efficiency. Large furnaces are more efficient than small ones, and the most practical design size limit apparently has not been reached. The largest under construction to date exceeds 300 ft high, with an inside hearth diameter of 45.3 ft, and an inner volume of 144,790 cu ft. This furnace, located in Japan, will have a daily rated capacity of over 10,000 short tons of hot metal. Figure 14 is a generalized section through a typical blast furnace.

Blast Furnace Smelting

Blast furnace smelting is a continuous operation

(Courtesy of Great Northern Railway Co.)

FIGURE 12.—Iron ore loading docks at Superior, Wisc.

FIGURE 13.—Loading iron ore carrier by a traveling conveyor system.

which normally is interrupted only when the refractory lining must be replaced, about every 3 years. The furnace is blown with hot air through tuyeres at the bottom of the bosh and is fed ore, coke, and flux through two bell mechanisms at the top; this permits charging without releasing the updraft of hot gases. A specially designed bell-type charging system is used for high-top-pressure blast furnace operation. Some high-pressure furnaces operate with top pressures up to 35.5 lb/sq in. The mixture of ore, coke, and flux moves slowly downward. As ascending gases heat the mixture, coke is burned, producing heat and carbon monoxide which reacts with the iron oxide in the ore, converting it to metal. At this stage the mass becomes molten; the acids, silica and alumina (in the ore) combine with the bases, lime and magnesia (in the flux) to form slag; the heavier metallic iron sinks to the bottom. Iron is tapped four or five times per day. The slag is tapped more frequently, as necessary.

Coke is the principal source of heat. It must be strong enough to support its own weight and the weight of ore and flux through the height of the stack. It is also the principal source of carbon monoxide, which reduces most of the iron oxide. Carbon dioxide may form momentarily from the coke in the lower part of the furnace, but it is unstable at temperatures in the smelting zone, and in the presence of carbon it follows the carbon dioxide-carbon monoxide equilibrium curve. Carbon dioxide formed at lower temperatures higher in the stack is relatively stable, so that the blast furnace exhaust gases invariably contain a mixture of the two carbon oxides. Enough of the carbon monoxide remains unreacted to yield 85 to 100 Btu per cu ft when the top or off gas is burned in air.

In modern furnaces, part of the heat is provided

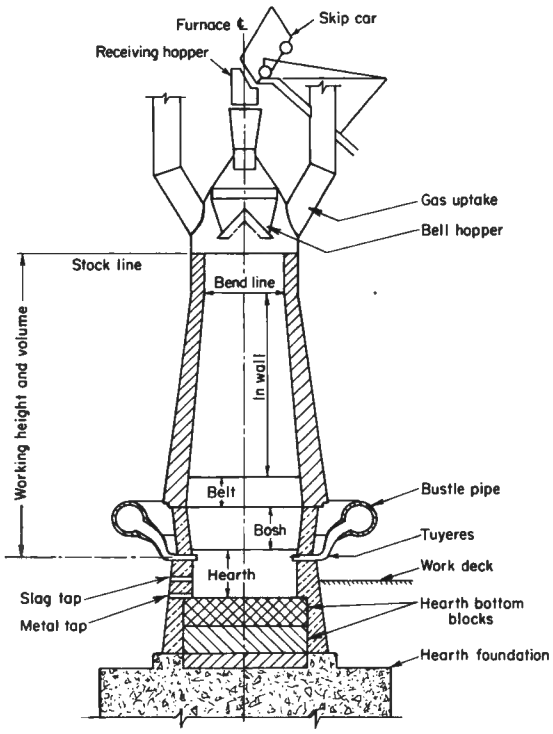


FIGURE 14.—Typical blast furnace cross section.

by natural gas, oil, or coal injected into the smelting zone at the bottom of the furnace. The fuels react with oxygen to produce heat. In effect, they serve partially to reduce the iron oxides, as the coke rate is correspondingly lowered.

Air blown into the furnace is first heated in checkerwork stoves that are fired with furnace top gas. Four stoves are common, and a furnace never has fewer than three. They are used alternately; one is heating the air while the others are being heated. Air is blown countercurrent to the products of combustion in the stoves. Approximately 2 tons of air are required per ton of pig iron produced. Hot blast temperatures range from 1,000° to 2,400° F, and the trend is to even hotter blasts.

Water vapor in the hot blast significantly influences operation of the furnace. It is used to control and prevent an excessive increase in temperature at the hearth; its decomposition with carbon may speed the rate of iron oxide reduction.

Limestone and dolomite are charged to the blast furnace to neutralize the acids, to provide a fluid slag, and to afford some control over the sulfur in the metal product. Flux particle size is compatible with that of the iron-bearing material and ranges from plus ⅛ in to minus 2 in. A weight-percent base-to-acid ratio $[(CaO + MgO)/(SiO_2 + Al_2O_3)]$ of 1.00 is optimum, considering all basic and acidic components in the ore, fuel, and flux.

Pig iron or hot metal produced by blast furnaces contains about 93 percent iron; it may contain 3.0 to 4.5 percent carbon, 0.2 to 4 percent silicon, 0.2 to 2.5 percent manganese, up to 0.2 percent sulfur, and up to 2.5 percent phosphorus. Blast furnace slag is chemically stable and suitable for use as structural ballast. Mixed with the other ingredients it is used in the manufacture of portland cement. Flue dust composition varies according to the operation of the furnace and the character of the charge, but it is principally iron oxides mixed with carbon. Practically all of it is returned to the furnace via sinter operations.

The chemistry involved in a blast furnace operation is extremely complex. Even after more than 300 years of use and intensive study in the last decade, the reactions are not yet completely known, nor are their interrelationships completely understood. Most of them are reversible, depending on concentration, temperature, and pressure. The more significant reactions and their heats in calories per gram-mol are given in table 10. Minus heats indicate an exothermic reaction (*13*).

Table 10.—Principal reactions in an iron blast furnace

Reaction	Heat of reaction, calories per gram-mol
1. $2\,C + O_2 \rightarrow 2CO$	[1] −52,800
2. $C + CO_2 \rightarrow 2CO$	[2] +41,250
3. $C + H_2O \rightarrow CO + H_2$	[2] +31,400
4. $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$	[1] −6,150
5. $Fe_3O_4 + 4CO \rightarrow 3Fe + 4CO_2$	[1] −2,800
6. $FeO + CO \rightarrow Fe + CO_2$	[1] −3,850
7. $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$	[2] +23,400
8. $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$	[2] +36,600
9. $FeO + H_2 \rightarrow Fe + H_2O$	[2] +6,000
10. $CaCO_3 \rightarrow CaO + CO_2$	[2] +42,850
11. $MgCO_3 \rightarrow MgO + CO_2$	[2] +24,250
12. $SiO_2 + 2C \rightarrow Si + 2CO$	[2] +157,400

[1] Exothermic.
[2] Endothermic.

The heat produced in equations 4, 5, and 6 is more than offset by the heat required to make the carbon monoxide reductant, equations 2 and 3. So burning of carbon, equation 1, and the sensible heat of the hot blast are the sources of energy for the chemical transformations, equations 2

through 12, and for physical transformation of the solids to fluid metal and fluid slag. Inasmuch as heat in the hot blast is obtained by burning top gases, it follows that all the heat of a blast furnace is obtained by burning carbon, plus hydrocarbons, if added. It is noteworthy that evenly sized burdens utilize CO more efficiently to improve the CO/CO_2 ratio and lead to lower temperature of the top gas. Furthermore, in furnaces using pellets in a carefully prepared burden, the top gas does not contain all the CO that could be used to heat the hot blast. Accordingly more energy can be put in these systems by supplementing the gaseous fuel in the hot blast stoves.

Additional energy to increase productivity can be supplied by increasing the oxygen concentration. This can be done by enriching the blast with oxygen, by operating the furnace at higher pressure, or both. Both methods have been proven to be technically beneficial. The high cost of oxygen has made its use economically unattractive. High-pressure operation is not yet standard practice, but is used in some of the newer furnaces.

Electric Furnace Smelting

Iron ore can be smelted in an electric-arc furnace wherein a solid carbonaceous material is the reductant and heat is supplied by electrical energy. The reactions involved are not as complex as those in a blast furnace. However, the process has not been subjected to the same intensive study as the blast furnace, and therefore is no better understood. Flux requirements from a standpoint of the base/acid ratio are the same as in a blast furnace. Practically all reduction in an electric furnace takes place in the hearth through direct contact of the oxides with carbon. Power consumption ranges upward from about 2,500 kwhr per ton of metal, so electric smelting is economically favorable only in areas having electric power at a cost less than that of heat from coke.

Direct Reduction

In some physical and economic environments iron ore can be reduced profitably by sponge-iron or direct-iron processes. Sponge-iron processes are named from the characteristic appearance of the reduced iron. Sponge-iron reduction takes place at temperatures slightly below the point of fusion, and the reduced iron does not reach the molten state. The most successful sponge iron processes start with high-grade material, so that the iron product need not be separated from gangue.

Direct-iron reduction processes originally were so called to contrast with blast furnace reduction. The term now is used for any process not categorized as blast furnace, electric smelting, or sponge iron. Technically, direct-iron processes are distinguished from sponge-iron processes by the temperature of reaction, which is above the point of fusion. That is, the reduced iron is molten in one stage of the process, although it is not necessarily accumulated in a liquid mass as in a blast furnace.

Sponge iron normally is produced commercially for high-grade melting stock to make specialty steels for processing to powdered, high-purity iron or for use in cementation processes to precipitate copper from leach solutions. Its relatively high cost in most economic environments precludes its use for other purposes. Furthermore, the benefits derived from using it for copper cementation in most instances are not sufficient to warrant the cost, depending on the price and availability of ferrous scrap.

Table 11 presents an elementary comparison of selected sponge- and direct-iron processes. These are among many that have proved technically feasible both on a small scale and in commercial installations. They were selected in preference to the others because they are illustrative of the principal reduction methods and are widely discussed in technical and trade publications. The Höganäs, Wiberg-Söderfors, and HyL processes have a long history of successful sponge-iron production, profitable because of the economic and physical environment in which they have been used and because of the premium quality of the sponge iron made.

Hoganas

In the Höganäs process alternating layers of iron ore, coal or coke, and limestone are placed in open vessels called saggers and reduced by carbon monoxide and hydrogen in a refractory kiln. The loaded kiln is brought to about 1150° C and held there for approximately 80 hr. Coal or coke in the saggers is burned with the controlled admission of air to provide about three-fourths of the heat. Approximately 15 million Btu is required per ton of sponge. The complete cycle from loading to unloading usually takes 10 to 12 days. The sponge product for use as melting stock is cooled and crushed. The metal is separated magnetically and then compacted. For ultimate use as metal powder the concentrated product is further reduced with hydrogen and then carefully sized to adjust its apparent density.

Wiberg-Soderfors

In the Wiberg-Söderfors process, iron ore is reduced with hydrogen and carbon monoxide in a shaft furnace. The upper part of the shaft serves as a preheater where the ore is brought to about 575° C by burning part of the spent reducing gases. The ore is reduced to wustite in a slightly endothermic reaction in the central part of the shaft and then reduced to sponge, approximately 85 percent metallic iron, in the bottom of the furnace.

The entire column of charge is supported on a water-cooled, eccentric rotating table that continuously discharges sponge around the periphery. A flat rotating ring moves the sponge to a single discharge point where it is sealed in airtight steel cans for later use in an electric arc melting furnace.

Reducing gas prepared from coke or other fuel and containing about 75 percent carbon monoxide and 21 percent hydrogen enters the bottom of the shaft at 950° to 1,000° C. Approximately three-fourths of the spent gas is removed at the top of the wustite zone; the remainder is burned by admitting air to the furnace. The gases removed are regenerated to carbon monoxide and hydrogen in a coke carburetor, then passed through a shaft of dolomite to remove sulfur before being returned to the reduction furnace. The processes consume about 9 million Btu per long ton of sponge.

HyL

The HyL process is a true sponge-iron reduction in that the temperature is never permitted to exceed the melting point of iron. The process requires high-grade iron ore or concentrate because all the impurities are carried through to an electric arc furnace where undesired components must be slagged off or go into the steel. The ore is reduced with reformed natural gas in four identical reduction reactors, each with a capacity of approximately 100 tons of raw ore. The system operates on a 12-hr cycle during which the reactors pass through four stages of 3 hrs each. In the first stage, the ore is preheated with hot gas and the reduction process is started. Most of the ore is reduced in the second stage. The remainder is reduced, and the charge takes on approximately 2 percent of combined carbon in the third stage. In the fourth stage, the ore, now sponge iron, is cooled, and the heat is recuperated and used to preheat the ore in the first stage. The final product is a sponge iron averaging about 85 percent metal from which 85 percent of the sulfur has been removed. The sponge is suitable for use wherever cold iron melting stock of this grade is employed. Normally all sponge is consumed at the plant site to feed electric steelmaking furnaces.

Krupp-Renn

The Krupp-Renn process can be classed as a beneficiating process as well as a direct-reduction process because it was developed for and is especially applicable to treating low-grade siliceous ores. Moreover, the reduced product is not completely suitable for use in steel furnaces because sulfur and phosphorus are not removed. The Krupp-Renn process had a period of relative popularity in Europe after World War II, but its use has been discontinued in areas having access to world iron ore markets. In the Krupp-Renn process, ore, flux, and carbonaceous fuel are fed together to an internally heated rotary kiln. The mixture travels countercurrent to hot reducing gases. It is heated to about 600° C in the first part of the kiln, reduced in the middle part at about 1,100° C, and forms metallic iron in the last part of the kiln at temperatures between 1,200° to 1,300° C. The iron, a semimolten mass, balls into lumps (luppen) surrounded by iron-free slag. The kiln is fired with excess oxygen to assure that the atmosphere in the luppen zone is oxidizing. Luppen are formed by the alternate oxidation of iron and the subsequent reduction of the iron oxide within the slag. The slag is expelled from the lower end of the kiln, where it is quenched with water sprays, crushed, and then passed through a magnetic separator to recover the luppen.

Luppen have diameters ranging from less than 0.1 in to 2 in; iron content ranges from 90 to 95 percent. Fuel and a fine-grained, iron-bearing fraction are recovered and recirculated. The temperature range must not be too wide or rings will form from slag buildup in the end section of the kiln.

SL/RN

The SL/RN process evolved from the essentially identical SL processes developed by the Steel Co. of Canada and Lurgi Gesellschaft of West Germany, and the RN process developed by the Republic Steel Corp. and the National Lead Co. Prior to the merger, the RN process concentrated on the reduction of low-grade iron ores with subsequent beneficiation, while the SL process was primarily for the reduction of high-grade iron ores. According to a statement issued by the National Lead Co., combining the SL and RN processes results in an improved direct-reduction process that is the result of pioneering work done

Table 11.—Comparison of selected iron ore direct-reduction processes

Process	Feed	Flux	Reductant source	Reducing temperature	Reducing equipment	Product	Developer
Hoganas	High-grade iron ore	Limestone	Coal or coke	1,150° C±	Saggers in ceramic kiln.	Sponge iron	Hoganas-Billesholms, Sweden.
Wiberg-Soderfors	High-grade iron ore	None	Coke or volatile fuel.	870° to 1,000° C	Shaft furnace	Sponge iron	Stora Kopparberg, Sweden.
HyL	High-grade lump iron ore	None	Natural gas	1,100° C±	Fixed-bed reactor.	Sponge iron	Hojalata y Lamina, Mexico.
Krupp-Renn	Siliceous iron ore	None	Solid carbonaceous fines.	1,250° C±	Rotary kiln	Luppen	Fr. Krupp, Germany.
SL/RN	Iron ore pellets	Limestone or dolomite.	Solid carbonaceous fines.	1,000° C±	Rotary kiln	High-iron briquets or pellets.	Stelco, Canada; and Lurgi, West Germany; Republic Steel and National Lead, United States.
Midrex	Iron oxide pellets	None	Natural gas	900° to 1,300° C	Shaft furnace.	Metallized iron pellets.	Midland-Ross, United States.
H-iron	High-grade iron ore fines	None	Coke oven gas or other H_2 source.	500° C±	Fluid-bed reactor.	Iron powder or briquets.	Hydrocarbon Research-Bethlehem Steel, United States.

by the respective companies over a long period of years. Undoubtedly, the improvements relate to the mechanics of the process and not to the metallurgical principles. The following is a detailed description of the RN pilot operation.

Ore, an excess of solid reductant, and a small quantity of limestone or dolomite is fed to a rotary kiln heated with an oil, gas, or solid fuel burner. The grade and grain size of the ore is not significant, except that retention time becomes excessive if the ore lumps exceed 1½ in. in diameter, and fine ore must be pelletized. The temperature gradient throughout the kiln is controlled by limiting the quantity of air available for combustion.

Kiln products are separated by screening, gravity, or magnetic processes, and the unused solid carbon reductant is cleaned and returned to the system. The iron-bearing portion is pulverized and separated magnetically, and the iron is pressed into high-density metallic briquets which are suitable melting stock for all steel-making operations. If green pellets are charged to the kiln the reduced pellet product is said to keep without noticeable reoxidation for 1 year under dry conditions.

Operating experience and further research on SL/RN technology has led to some refinement in the foregoing concept. Metallurgists of Lurgi Gesellschaft reported on SL/RN raw materials in 1969 as follows:

> The selection of ore type is limited only by the method of processing the reduced ore. If sponge iron is used in the electric arc furnace, the gangue content of the ore should not exceed 5 percent. However, when the reduced ore is treated in a blast furnace or in an electric ironmaking furnace, the gangue content is restricted within economic limits. . . .
>
> . . . Practically all solid carboniferous agents except highly caking coals can be used as reducing agents. The most important prerequisite is that the ash fusion temperature is about 100° C above the working temperature, i.e. 1200° C. . . .
>
> . . . From a technological viewpoint, the ash and sulphur contents are unlimited. However, for economic reasons, coals with a low ash and sulphur content are preferred.

Midland-Ross

The Midland-Ross and the Armco reducing processes are similar to the HyL process in that the reduction is made with reformed natural gas.

The Midland-Ross Corp. process, designated Midrex, converts high-grade iron ore fines into green pellets which are inundated with heat and then moved continuously through a vertical shaft reduction furnace. The descending pellets contact hot, reformed natural gas in countercurrent flow during the single-pass trip. This takes several hours at a temperature which approaches a maximum of 1,300° C.

Armco Steel Corp. holds patents on a similar process using an H_2–CO atmosphere to reduce iron oxide pellets at 1,300° to 1,800° F. in a shaft furnace (*6*). Armco also has operated a fluidized reactor pilot plant for ore reduction.

H-Iron

The H-iron process, developed by Hydrocarbon Research, Inc., Bethlehem Steel Corp., utilizes hydrogen as the reductant in a fluid-bed reactor held at about 500 psi and about 500° to 550° C. The primary use of the units operated to date has been to produce a high-grade iron powder (about 95 percent reduced), for metallurgical uses.

New Processes

Esso Research and Engineering Co. and U.S. Steel Corp. developed fluid iron ore direct-reduction processes similar to the fluid iron process. The Esso process, designated FIOR, has a multistage reducing reactor system and utilizes reformed gas produced from either natural gas or an oil fraction. The product is a high-density briquet with an iron content exceeding 90 percent. The fluid-bed process of U.S. Steel Corp., the Nu-Iron process, uses a reducing gas prepared from natural gas or other hydrocarbon fuel source to reduce minus 10-mesh ore at 650° to 700° C in two stages. The high-iron product is 90 to 95 percent metallized. It is briquetted hot; then cooled under inert gas.

The metallization of iron in the reduction process reaches an economic cutoff point for use in a blast furnace at about 85 percent in most processes. To increase this cutoff point may make the operation unprofitable. However, potential saving in transportation costs, if the product is made and transported great distances, and the increase in blast furnace productivity resulting from greater reduction also are factors to consider. Metallized pellets for use in a steel furnace may be further reduced.

The Dwight-Lloyd McWane (D-LM) carbonizing process has been publicized as an advanced iron oxide partial-reduction method. In the D-LM process a predetermined mix of iron ore fines, flux, and coal is formed into sized green pellets by

means of a disc-type pelletizer. The size may be as large as 1-in, which is favored for deep-bed carbonization. The pellets are fed to a traveling grate. Carbonization is obtained during the grate travel, which requires about 12 min, as the pellets are heated in stages to above 1,000° C with a controlled downdraft. Under proper control the carbonized pellets are self-fluxing and self-reducing, ready to be charged to an electric furnace for conversion into foundry iron. Iron oxides in the pellets may be reduced 50 percent or more by the carbonization treatment. McWane Cast Iron Pipe Co. in 1969 sponsored construction of a 600-ton-per-day capacity plant at Mobile, Ala., to utilize the D-LM process. However, the plant was sold to the Air Reduction Co. late in 1970 for the manufacture of ferroalloys.

Bureau of Mines researchers, working to produce a superior blast furnace feed, developed a simultaneous reduction-induration kiln process that has proved successful in a small pilot plant. Iron ore concentrate balled with bentonite joins a stream of lignite or anthracite coal and a trickle of limestone to enter a rotary kiln held at a maximum temperature of 2,100° F. The kiln product, composed of hardened and reduced pellets mixed with char, is cooled and screened to recover clean pellets and char. The pellets from a high-grade concentrate contain about 85 percent total iron, 70 percent of which is metallic. They are hard and durable, but as all reduced metallic iron products, the pellets must be kept dry to prevent reoxidation.

A 23-percent saving in transportation cost results from upgrading 65 percent iron ore to 85 percent iron. Tests conducted by the Bureau of Mines in its experimental furnace at Bruceton, comparing material containing 89.5 percent iron with that containing 65 percent iron, indicate a saving of 45 percent in coke and a 75-percent improvement in productivity. Graff and Bouwer estimated the total cost of producing hot metal from prereduced pellets at $30.98 per net ton compared with $33.84 per net ton from conventional pellets (*10*). Perhaps more meaningful is their estimate of 11.5-percent annual profit on an original investment in a 1-million-ton-per-year hot-metal plant using prereduced pellets, compared with 8.5-percent annual profit in a plant using regular pellets. In estimating that hot-metal costs could be reduced about $2.00 per ton through use of prereduced Mesabi pellets, gaged by conventional practice, Bureau of Mines researchers are substantially in agreement with Graff and Bouwer (*9*).

Later Bureau of Mines reduction research has been designed to develop methods for producing reduced iron material that can be used economically in steel furnaces. This work was in progress at the beginning of 1971.

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CHAPTER 5.—PRODUCTION, CONSUMPTION, TRADE, AND USE PATTERNS

WORLD PRODUCTION

Iron is produced from open pit and underground mines. The latter range in size from mines producing only a few hundred tons of selected high-grade ore per year from thin veins underground to those producing tens of millions of tons of low-grade ore from massive, bedded, surface deposits. Large underground iron mines are the exception rather than the rule, but production from those in the United States, Sweden, and the U.S.S.R. contributes significantly to the world's total output.

North America

United States

Iron mines in the United States are grouped in the Lake Superior, Northeastern, Southeastern, and Western districts for convenience in the statistical reporting, but only the Lake Superior district mines are bound by similar geologic genesis. (See table 3.)

Lake Superior District—The Lake Superior district covers Minnesota, Michigan, and Wisconsin. Its mines are in or adjacent to seven recognized mining ranges: Mesabi, Spring Valley, Vermillion, and Cuyuna in Minnesota; and Marquette, Menominee, and Gogebic in Michigan; the latter extends into Wisconsin. The mines on the Vermillion and Gogebic Ranges were shut down in 1965 and only a few mines on the Cuyuna have operated since 1962. Cuyuna Range mines did not produce in 1970. In 1968 mining was again started in Wisconsin in a new area near Black River Falls.

Open pit taconite mines on the Mesabi Range have produced by far the largest part of domestic ore than can be credited to one segment of the industry. Their approximate output can be traced through the statistical record of magnetite concentrate production. Taconite crude ore contains approximately 30 percent total iron, of which about 22 percent is in the form of magnetite. With current practice (1970) practically all the magnetite is recovered; therefore, the mines operate on a concentration ratio of approximately 3 to 1, and the pellets produced contain 60 to 65 percent iron. The usable iron ore output of the mines is limited by the capacity of the attendant concentrating and pelletizing plants. High capital costs of these plants makes operating at rates much below capacity unprofitable, so the annual taconite mine output in all probability will not be much less than the total required to reach the pelleting capacity shown in table 10.

All other iron mining on the Mesabi Range has been in open pits since 1964. These operations produce direct-shipping iron ore and iron ore concentrate, averaging about 53 percent iron from relatively soft crude containing 40 to 50 percent iron. Concentrating plants are small and inexpensive compared with those treating taconite, so these mines and others like them on the Vermilion and Cuyana Ranges provide the flexibility needed to adjust production to consumption. The trend in output from these lower grade, soft-ore mines has been downward since 1957 and probably will continue downward because the market for the grade of ore they produce is shrinking.

Owing to the size, grade, and attitude of the ore body, and to its proximity to the ore dock at Marquette, the Mather underground mine on the Marquette Range, has proved the exception to the decline in underground mining. Its output plus that of the specular-hematite jaspilite and magnetite-jaspilite open pit mines have kept the mining industry of the Upper Peninsula of Michigan relatively stable.

Northeastern District.—The Grace and Cornwall underground mines in Pennsylvania and the Benson open pit mine in New York produce most of the usable ore in the Northeastern district. All three produce magnetite and hematite concentrates. The Grace and Cornwall mines produce pyrite and pyrite-chalcopyrite byproducts respectively, and both carry iron ore processing to a pellet product.

Southeastern District.—Iron ore production in the Southeastern district gradually was cut to about one-third of its former output when ore from Venezuela was imported into the Birmingham steel district beginning in 1955. Underground mines in the Big Seam of the Clinton Formation have been shut down. The district's output now

is solely from small open-pit, brown iron ore mines. The Pyne mines in Jefferson County, Ala., was the last of the underground mines in the Southeastern district.

Western District.—Meramec Mining Co.'s Pea Ridge underground mine in Missouri, the Sunrise underground mine and Atlantic City open pit taconite mine in Wyoming, the Cedar City and Iron Springs open pit operations in Utah, and the Eagle Mountain open pit mine in California are the principal producing mines in the Western group. Their capacity is limited by ancillary beneficiation plants. Pellets are produced from Eagle Mountain and Atlantic City concentrate.

Canada

Canadian iron ore currently is produced in Newfoundland (including Labrador), Quebec, Ontario, and British Columbia. In general, the iron mining areas in Eastern Canada are comparable to the Lake Superior district in the United States. As a matter of fact, the Steep Rock and Caland Ore Co. Mines in Ontario are believed to be in an extension of the Mesabi Range. The ores are similar in grade and structure to Mesabi soft ores. The mines had about the same output flexibility as similar open pit mines on the Mesabi, but the need to beneficiate and agglomerate their ores to meet market requirements is binding them to a rigid mining schedule. The Algoma Ore properties in Ontario, being mostly siderite deposits, are unique, but the Griffith, Sherman, Adams, National Steel Corp. of Canada Ltd., and Marmoraton Mining Co. mines are taconite operations. All the latter beneficiate the ores to pellets.

The Wabana underground iron mine on Bell Island in Newfoundland was shut down in 1966, and there seems to be little chance that it will be reopened under present competitive conditions.

The Iron Ore Co. of Canada open pit mines at Schefferville in the Quebec-Labrador region are in soft Mesabi ores with typical flexibility of output. The company's Carol operation, the Hilton Mines Ltd. and the Quebec Cartier Mining Co. mines in Quebec are taconite-jaspilite operations with output flexibility restricted by large, expensive beneficiation plants. However, Quebec Cartier does not yet carry processing to an agglomerated product, and the ores of all the mines are easier to concentrate than are the Mesabi taconites.

All the iron mines in British Columbia except the Texada, Coast Copper, and Westfrob mines are typical medium-size, underground magnetite mines. The outcrops have been mined in open pits to the economic limit, and all have changed or are in the process of changing to underground mining. The Coast Copper Co. mine produces magnetite concentrate as a byproduct of copper mining, and the Texada mine produces a byproduct copper concentrate from its magnetite mining operations.

Canadian iron ore mining companies and their mines, by province, are as follows:

Newfoundland—
Iron Ore Co. of Canada, Carol mine, and Wabush Mines, Scully mine;

Labrador-Quebec—
Iron Ore Co. of Canada, Schefferville mines;

Quebec—
Hilton Mines, Ltd., Hilton mines, and Quebec Cartier Mining Co., Lac Jennine;

Ontario—
Adams Mine, Algoma Ore Properties, Caland Ore Co., Falls Bay, Cleveland-Cliffs, Sherman mine, Marmoraton Mining Co. Ltd., Marmona mine, National Steel Corporation of Canada, Moose Mountain mine, The Steel Co. of Canada, Griffith mine, and Steep Rock Iron Mines Ltd., Hogarth, Roberts;

British Columbia—
Bynnor Mines, Coast Copper Co., Benson Lake mine, Jedway Iron Ore, Texada Mines Ltd., Westfrob Mines Ltd. (Falconbridge Nickel), and Zeballos Iron Mines.

Mexico

More than 90 percent of the iron ore produced in Mexico is mined from open pits at Cerro de Mercado in Durango, at La Perla in Chihuahua, and at El Encino in Jalisco. The remainder, also mined from open pits, is produced from small mines in Coahuila and Zacatecas. At present (1970), all the iron mines have typical open pit flexibility, although beneficiating and agglomerating plants have been installed at two locations. The combined capacity of the mines is about double the internal requirements.

A government permit must be obtained to export iron ore, and no significant quantities have left the country in recent years. Future mine expansions will probably depend upon domestic iron and steelmaking ore requirements.

South America

Argentina

More than 90 percent of the iron ore produced in Argentina is mined from the Puesto Viejo open

pit and the 9th of October underground operations in the Zapla area of Jujuy. These mines are barely adequate for the local industry, and there seems little chance that the district's capacity will be increased significantly in the future.

The Argentine Government has been pushing development of the Sierra Grande deposits in Rio Negro Province to lessen dependence on imported ore. An open pit operation to incorporate extremely fine grinding and pelletizing is planned. The plant will be designed to produce 2 million tons of 65-percent-iron pellets per year.

Brazil

Brazilian iron ore mines range from large, modern, highly mechanized operations that produce more than 1 million tons per year to small, primative hand-powered operations that produce less than 10,000 tons per year. Practically all the mines are in the Congonhas and Itabira districts of the Iron Quadrilateral in Minas Gerais. The ore is mined from open pits with very little overburden or waste except fines. The fines, of the same grade as the ore, 68 percent iron, were not utilized prior to 1966.

Mining districts or areas in the Iron Quadrilateral have developed mainly through availability of transportation rather than availability and quality of ore. Since 1950 output of the Congonhas district has been limited by the quantity that could be hauled over the Estrada de Ferro Central do Brazil, and output of the Itabira district has been restricted by the quantity that could be hauled over the Vitória-Minas railroad. The stocks of high-grade fines at the large mines in both districts exceed the quantity of highest annual output, so there is no doubt that for a year or two any one of the mines easily could produce at more than double its past rate, if transportation is provided and fines are accepted.

The Caué mine in the Itabira district, owned and operated by the Cia Vale do Rio Doce and with capacity exceeding 15 million tons per year, is by far the largest iron mine in Brazil. Caué ore is crushed and screened in plants integrated with a 42-in belt conveyor system from the mine to a 4 million-ton ore storage and trainloading plant. The primary crusher and the belt car-loading feeder have nominal capacities of 2,000 tons per hour. Cia Vale do Rio Doce operates a 2 million-ton-per-year pelletizing plant at Tubarão harbor near Vitória. Plans to double the plant capacity by 1972 have been announced.

Casa de Pedra mine in the Congonhas district with capacity of about 1½ million tons per year is the second largest iron mine in Brazil. It is owned and operated by the Cia Siderúrgica Nacional. There the ore is mined with 2½-cu yd shovels, crushed and screened, and moved on a 2½-mile aerial tram to a rail loading point. Car-loading capacity is 1,200 tons per hour.

Mines of the Piracicaba area, the Andrade and the Morro Agudo, owned and operated by Cia Siderúrgica Belgo-Mineira and its subsidiaries are probably next in size among Brazilian iron mines. Andrade ore is mined with 1¾-cu yd shovels, and crushed and screened at the mine. Its capacity is about one million tons per year. Morro Agudo ore is mined with 2½-cu yd shovels and transported in 35-ton trucks 7 miles to a crushing and screening plant. Its capacity probably exceeds 1 million tons per year.

Pico do Itabirito, Mutuca 4, and Aguas Claras of the Itabirito group of mines in the Congonhas district, owned and operated by Minerações Brasileiras Reunidas, presently comprise productive capacity approximately equal to mines of Belgo-Mineira in the Piracicaba group. Their potential is much greater. Minerações Brasileiras Reunidas is owned 49 percent by Hanna Mining Co. through its subsidiaries and 51 percent by the Augusto Antunes Group through its subsidiaries. Pico do Itabirito is equipped with 2-cu yd shovels and 10-ton trucks; its capacity is about 300,000 tons per year. Mutuco 4 is equipped with 2½-cu yd shovels and 12-ton highway and 35-ton off-highway trucks; its capacity is about 750,000 tons per year. Aguas Claras has been of principal interest to the Cia de Mineração Novalimense (Hanna).

The Fabrica open pit mine in the Congonhas district, owned and operated by Cia Mineração de Ferro e Carvão, subsidiary of August Thyssen-Hutte A.G., uses 3-cu yd shovels and 25-ton trucks. Its capacity exceeds 500,000 tons per year.

The Mutuca mines in the Paraopeba Valley area are owned by Cia Siderúrgico Mannesmann and operated by its subsidiary Mannesmann Mineração. They are equipped with 2½-cu yd shovels and 10-ton trucks. The ore is trucked about 3 miles to a crushing and screening plant and then moved 3½ miles on an aerial tram to a blast furnace at the Barreiro Works, near Belo Horizonte.

Chile

The iron mining industry of Chile is confined to an area about 250 miles long and 50 miles wide, stretching from 26° south latitude in Atacama Province to 30° south in Coquimbo Province.

The mines, all open pit, range in size from small individual hand-picking operations in float ore, producing a few hundred tons per year, to completely mechanized operations producing several million tons per year. In the aggregate, they have the flexibility of output usually associated with open pit mines that are unrestricted by ancillary concentration plants. However, the potential output of some individual mines is limited by the capacity of transportation facilities.

El Algarrobo and Penoso mines in Atacama Province 135 miles from Huasco are owned and operated by Cia de Acero del Pacífico S.A. They are worked as one unit. Parts of operations are contracted to independent concerns. The ore is mined with 4½-cu-yd shovels loading into 35-ton trucks. It is graded, crushed, and screened at the mine to produce sinter fines and blast furnace feed. Fines and ore containing less than 56 percent iron are stockpiled. Capacity is about 4 million tons per year. A dry magnetic concentrator upgrades the reject fines to salable material.

The Carmen mine in Atacama Province 30 miles from Chañaral is owned and operated by Cía Minera Santa Bárbara. It is equipped with 2½-cu-yd shovels and 27-ton trucks. The ore is crushed and screened at the mine and carried 7½ miles on a 24-in conveyor belt to railway loading bunkers at the Hermotita mine. Mine capacity is about 1 million tons per year; the belt carries 400 tons per hour, with surges to over 500 tons per hour. It could probably handle double the present Carmen mine output without trouble.

Raul and El Adrianitas open pit mines in the Cerro Las Adrianitas in Atacama Province are operated as a unit. Cía Minera de Atacama, a subsidiary of Yawata Iron and Steel Co. Ltd., and Mitsubishi Steel Mfg. Co. Ltd., is the operating company. The ore is crushed and screened at the mine. Total capacity is approximately 700,000 tons per year.

El Romeral in Coquimbo Province 40 miles north of La Serena prior to nationalization was owned and operated by Bethlehem-Chile Iron Mines Co., a subsidiary of Bethlehem Steel Corp. The ore is mined with 4- and 6-cu yd shovels loading into 27- and 32-ton trucks. It is crushed and screened at the mine and upgraded with a magnetic concentrator.

Peru

Iron ore mining in Peru was reduced to a one-company industry, Marcona Mining Co., operating the Marcona mine, with the closing of the Acari mine by Pan American Commodities S.A. in 1967.

Marcona is on the coastal plateau 2,400 feet above sea level, 250 miles south of Lima. It actually is seven major mines or pits. More may be developed in the future. The iron-bearing zone is 12.5 miles long and from 2.5 to 3.7 miles wide. The operation is complicated by weathered and primary ores, which must be mined and processed separately.

Marcona has typical open pit flexibility in both the primary and weathered ore zones; 2½-, 4-, 6-, and 15-cu yd shovels load 30-, 35-, 60-, and 100-ton trucks. Flexibility extends beyond the pits although the increasing production of primary ore and the consequent need for more sophisticated beneficiation may establish both upper and lower output limits. The upper limit, however, will be much above the normal planned output. Capacity is about 12 million tons per year.

Oxidized ore is crushed at the mine and then transported in 55- and 75-ton trucks 17 miles to stockpiles and a fines plant at San Juan. The fines are upgraded with jigs, spirals, and wet magnetic separators.

Primary ores are crushed at the mine and transported by a 36-inch, 2,000-ton per hr capacity, slope-length conveyor, which is 7.77 miles long and which drops 1,900 feet to the beneficiation plant at San Nicolas. The ore is treated at the plant by third- and fourth-stage crushing, grinding, magnetic cobbing, heavy media separation, and magnetic concentration. The plant has the capacity to produce more than 3 million tons of pellets per year.

Venezuela

Cerro Bolívar and El Pao open pit mines south of the Orinoco River in the State of Bolívar constitute the iron ore industry of Venezuela. Cerro Bolívar is owned and operated by the Orinoco Mining Co., a subsidiary of U.S. Steel Corp. Ore is mined by 6-, 8-, and 9-cu yd shovels that load into 38- and 50-ton trucks or into 90-ton railway cars. The ore is hauled 90 miles by rail to Puerto Ordaz on the Orinoco river. Crushing facilities are available at the port, but most of the ore is shipped without further treatment. The mine has usual open pit flexibility; production capacity is governed by transportation. With present equipment, the capacity is 18 to 20 million tons per year. The Orinoco Mining Co. is constructing a plant to produce 1 million tons of prereduced iron ore annually. Reportedly, the final product will be hot-pressed briquettes.

El Pao is owned and operated by the Iron Mines Co. of Venezuela, a subsidiary of Bethlehem Steel Corp. Ore is mined by 4-cu yd shovels loading 22- and 30-ton trucks. The ore is crushed to minus 4 in and screened to remove the minus-½-in material at the mine; then it is hauled by rail 35 miles to Palua, a port on the Orinoco River. Production capacity with present mine and crushing equipment is about 4 million tons per year.

Europe

European iron ore production is divided about evenly between open pit and underground mines. The mines range in size from small to very large, but most of them produce more than 1,000 tons per day. On the whole they are equipped with modern mining machinery, but the argillaceous nature of the ore mined outside the U.S.S.R., Sweden, and Norway has restricted application of modern beneficiation equipment. On the other hand, many of the iron mines in the U.S.S.R., Sweden, and Norway are equipped with the latest concentrating and agglomerating equipment. European iron ore production is more stable than that of the United States because the high-grade producers operate at capacity to supply the continent's need for iron, and the low-grade output is maintained at a level deemed desirable according to local political and economic needs.

European Coal and Steel Community

Activities of the European Coal and Steel Community (E.C.S.C.—Belgium, France, West Germany, Italy, Luxembourg and the Netherlands) do not directly affect the conduct of the iron ore industries of member countries. The industries are indirectly influenced by mutual research interest, labor exchange, and freedom of iron and steel trade across national boundaries. Iron ore is produced in all the Community countries except the Netherlands. All the ore is low grade by modern standards and only France produces a significant quantity in excess of its own needs. Italy and Belgium together produce less than 1 million tons per year. Belgian mines are within a few miles of the Luxembourg border and their output is reported with those in Luxembourg. Italian iron ore is mined principally from open pits on Elba Island and from the Liconi deposits in the Valle de Cogne (Aosta).

France—More than 94 percent of the iron ore produced in France is mined from the minette ores of Lorraine in the Briey, Longwy, and Nancy Basins. The remainder is produced from similar siliceous ores in western France and from small mines in the carbonate deposits of the Pyrenees. In general the Lorraine mines were started in open pits on the outcrops, working down the dip. When the economic stripping ratio was reached, the miners went underground through adits, following the downward-dipping iron formation and extracting the ore in a classical room-and-pillar pattern. When the economical adit haulage distance was reached, vertical shafts were sunk to remove the ore. The newer and deeper mines were developed directly through shafts, but the mining methods used are the same as in the older ones.

The French iron mining industry has been systematically modernizing and mechanizing since World War II. Jumbo hydraulic-boom drill mounts, mechanical loaders, scrapers, shuttle cars, trackless haulage, roof bolts, and conveyor belt transportation systems are now used, but some of the operations do not yet have optimum equipment balance.

From a practical viewpoint, all Lorraine iron mining is underground with the usual restrictions on mine output flexibility. Its flexibility is further restricted by the capacity of aerial trams that serve many of the mines between mine and steel mills. Accordingly the capacity of French iron ore mines is judged to be less than 80 million tons per year, which is 14 million tons more than the peak 1960 output.

Luxembourg—Luxembourg's iron mines are actually an extension of the French Lorraine district. They are in the same formation and some of the surface plants are within sight of each other. The mining methods in the two countries are identical but the Luxembourg mines are not as well equipped as those in France. Mine portals in Luxembourg are at the steel mills. Luxembourg's iron mine capacity does not exceed 9 million tons per year and probably is closer to 8 million tons per year.

West Germany.—West Germany's iron ore mining industry apparently is phasing out in much the same way as the direct-shipping and soft ore mines of the United States. The trend is demonstrated strikingly by the number of operating mines; 62 were operating in 1954, and that number had declined to 30 in 1963 and to 10 in 1968.

The Peine Salzgitter district now produces more than 80 percent of West Germany's iron ores. Mines there are both open pit and underground. Most of the ore is now being mined underground by block-caving, modified cut-and-fill, and room-and-pillar methods. Capacity is restricted by underground mining, by local transportation

equipment, and by attendant roasting and beneficiation plants. Less than 19 million tons was produced in 1961, and from a practical viewpoint, 1970 production is closer to 10 million tons than to past peaks.

Austria

Most of Austria's iron ore is produced in the open pit section of the Steirische-Erzberg mine. The mine was completely mechanized through the Marshall Plan in 1951 and a 400-ton-per-hr heavy-media plant was added in 1956. Judging by the reported capacity of the concentrating plants, the mine and ancillary beneficiation facilities have a practical capacity of about 3 milion tons of ore per year.

Czechoslovakia

The iron mines of Czechoslovakia are in northern Bohemia and the Spis-Hamry Basin in Slovakia. The mines are small and as far as is known have not yet been equipped with modern mining machinery. The absolute capacity of the industry probably does not exceed 4 million tons per year; production in 1969 was about 2 million tons.

Norway

Norway's iron ore industry essentially is state owned. The Sydvaranger open pit mine, capacity 2.4 million tons concentrate per year, Rana Gruber open pit, capacity 750,000 tons pellets per year, and the Fosdalen and Rodsand underground mines, capacities 400,000 tons and 165,000 tons of concentrate per year, respectively, are the principal producers. Since other mine output is inconsequential, Norway's overall practical mine capacity is 3.7 million tons per year.

Sydvaranger is a typical taconite mine, with attendant beneficiating facilities to produce high grade concentrate. Part of the concentrate is sold as such and the remainder is pelletized in a new 1.2-million-ton-per-year-capacity pelletizing plant. Physical properties of the deposits are similar to the iron formation of the Lake Superior district, although the rock may not be quite as hard. Four 7½-in down-the-hole drills were added to the mine equipment in 1965. Fifteen 100-ton trucks and four 9-cu yd shovels were put in service at the same time. The mine had been operated previously with 4½-cu yd shovels and 35- and 22-ton trucks.

Rana-Gruber is also a taconite operation where concentrates are pelletized. Fosdalen ore is beneficiated by magnetic separation. The concentration ratio is about 2 to 1, so Fosdalen's capacity actually is over 500,000 tons per year.

The iron ore industry of Norway does not have built-in flexibility. Production could be cut back at a sacrifice in efficiency, but it could not be expanded significantly on short notice.

Poland

Poland's iron mining industry is in the following districts, in order of significance: Czestochowa-Klobuch, Kielce, and Leczyca. All the mines are small and underground. Their combined capacity is approximately 3 million tons per year. However, ability to increase output on short notice is slight.

Spain

The iron mining industry of Spain is mainly in the four following districts: Granada, Vizcaya-Santander, Leon, and Teruel-Guadalajara. These account for more than 70 percent of Spain's iron ore output and contain all the large mechanized mines.

The Marquesado open pit mine in Granada is the largest iron mine in Spain. The ore is loaded with an 8-cu m front-end loader, and hauled in the pit with 50-ton trucks. The overburden is much thicker than the average on the Mesabi. It is pushed from 30-m benches into a mobile rock belt loader with buldozers and is removed from the pit by conveyor belts; a portable stacker forms the spoil pile. Iron ore has previously been produced in the district by sublevel caving of scattered underground shoots and cut-and-fill stoping, and from other open pits. However, the Marquesado open pit mine now is the only producer of any significance in Granada.

Vizcaya-Santander is the oldest iron ore district in Spain and currently produces the most ore. However, the mines may be nearing the end of their production. The hematitic, low-phosphorus ore which made the distrirt famous is depleted and the mines are working in siderite-carbonate ores, most of which must be dewatered and/or calcined. Open pit mining predominates. On the whole the mechanical equipment is outdated. The district does not have usual open-pit flexibility to increase production.

Coto Wakner and Coto Vivaldi underground mines near Ponferrada are the principal mines in Leon. They are reported to have a combined capacity of 1 million tons per year.

The Teruel-Guadalajara district is dominated by the Ojos Negros open pit mine owned and operated by Cia Minera de Sierra Merera S.A. Ojos

Negros is equipped with British-made power mining equipment. Reported capacity is 1 million tons per year. The mine has typical open pit flexibility. A pelletizing plant with a capacity of 370,000 tons per year was scheduled to start operating in 1971. A privately owned rail line that transports the ore to the port of Sagunta can haul much more than 1 million tons per year.

Sweden

The iron mines of Sweden are among the most highly mechanized and efficient in the world. Most of the ore is mined underground. Sublevel caving is the preferred and dominant mining method with block caving, slice-and-shrinkage stoping, and several modifications of each being used where the shape and attitude of the ore body makes them especially applicable. Ore preparation and beneficiation plants, rail transportation, ship loading docks, and the northern climate serve to limit flexibility of output.

Luossavaara-Kiirunavaara A.B. (LKAB) with the Kiruna, Malmberget, and Svappavaara mines and the Gränges Co. with the Grängesberg and Strassa mines produce more than 90 percent of Sweden's iron ore.

Malmberget was first mined by open pit methods. Mining methods vary to fit the irregular lenses of ore, but the management has worked toward standardization to sublevel caving, which is also used at Kiruna. The ore is crushed and then concentrated in a dry-cobbing circuit. Middlings, about one-fourth of the total, are ground and then concentrated in a wet circuit. Concentrate is pelletized at Kiruna and Malmberget.

Svappavaara is an open pit mine developed from 1963 to 1966. The ore is mined with 5-cu yd shovels loading into 40- to 45-ton off-highway trucks. About one-third of it is concentrated and pelletized; the remainder is shipped as lump ore.

The three LKAB mines have a combined annual capacity of more than 25 million tons. Malmberget's capacity is at least 4.5 million, but output has not reached that figure during the last few years.

Overall, LKAB is expanding its capacity by adding new plants and raising productivity. In doing so the company is also raising the quality of its products. As its operations are integrated, there is not much room left for flexibility. Output can be cut back only at a sacrifice in efficiency. It is being increased at a rate judged optimum by the management. This rate cannot be stepped up.

The Grängesberg and Strassa mines are underground. Both are equipped with modern machinery. Grängesberg is worked by sublevel block-caving and shrinkage-stoping methods. The ore is concentrated magnetically. Strassa is worked by modified sublevel and slice stoping. The ore is concentrated magnetically and pelletized. Pelletizing capacity is 2 million tons per year. The Grängesberg mine has unusual output flexibility for an underground mine, because the stopes are relatively small and therefore production can be cut back without excessive loss of efficiency. Neither mine can increase output significantly on short notice. Their combined practical capacity is 4 million tons of concentrates and pellets per year.

Other iron mines in Sweden are small. The Stallberg Group (Stallberg, Stripa, Idkerberg, and Forsbo mines) and the Dannemora mine are the best known. The Stallberg mines are equipped with modern equipment and make a high-grade product. Their combined output is less than 1 million tons per year, and their capacity is not much more than that. Dannemora produces about 500,000 tons of 45- to 49-percent iron ore and concentrate per year.

U.S.S.R.

The iron ore industry of the Soviet Union surpassed that of the United States in the quantity of usable ore produced in 1958, and in the quantity of crude ore produced in 1961. The average grade of usable ore is about the same as in the United States, but the average grade of crude is higher. Soviet iron ore in 1968 was mined in 58 open pit and 66 underground mines. The mines ranged in size from less than 500,000-ton-per-year capacity to huge open pit combines with 13.5-million-tons-per-year capacity. Most of the underground mines are relatively small, but Gigant Glubokaya (Deep Giant), with a planned annual capacity of 7.4 million tons, is the world's second largest underground iron ore mine.

In the last decade the Soviet iron ore industry has been expanding and producing at a maximum rate within the framework of a communistic economy. Accordingly the existing mines have little flexibility to increase output, although production can be adjusted downward with ease. Planned plant expansion is not yet completed, so mine output capacity is expected to go up with time.

Soviet iron ore is obtained from mines in the following seven general areas: Ukraine, Central European Russia, Kola Peninsula, Ural Mountains, Kazakhstan, West Siberia, and Eastern Siberia. These areas are selected for ease of

discussion. They conform to the broad division commonly used by the Soviets in describing their iron ore industry and serve roughly to identify the industry's geographic distribution.

Krivoi Rog Basin of the Ukraine is the principal iron ore producing district of the Soviet Union. It is similar to the Lake Superior district in that the mines are both underground and open pit and that practically all the ore is beneficiated in one way or another. Moreover, the trend is toward larger mines, the mining of lower grade ore, and larger beneficiation plants producing a higher grade concentrate. However, in contrast to the Lake Superior district, most of the concentrates are sintered rather than pelletized.

Underground mining at the Gigant Glubokaya, is comparable to the "Giant" Mather mine on the Marquette Range. Its planned capacity of 7.4 million tons annually is more than that of the Mather mine. U.S. mining engineers have found the Gigant well planned, equipped, and organized.

The open pit mines use 3-, 4-, and 6-cu m shovels. Incomplete information indicates that rail is the principal means of haulage. Trucks, skips, and conveyors are used in the deeper open pit mines. More than half the ore is drilled with tungsten carbide bits on down-the-hole equipment.

Underground mines use rotary equipment for ring drilling in sublevel, inclined, flat-bottom stopes. Mechanical loaders work on the haulage levels. Modified block-caving and open-stoping methods are used where applicable. All the underground mines have modern machinery. Mechanical loaders in place of chutes now could be standard practice.

The Krivoi Rog district probably had capacity to produce 83 million tons of usable ore per year in 1966. Plants constructed since then may have raised capacity to 100 million tons. The open pit mines provide some flexibility of output, but the newer mines are bound to wet-magnetic concentrating plants which provide a rigid upper limit. Most of the underground mines apparently produce at their hoisting capacity.

Mines in the Kerch district are all open pits. The ore is mined by chain excavators and beneficiated by washing. The district's total capacity with present equipment is approximately 5 million tons of washed ore per year.

Mines in the Kursk district of Central European Russia are open pits. Excessive water has prevented large-scale underground mining to date. Ore is crushed and graded but not concentrated at Lebedinsk and Mikhoilansk, the principal mines. Two unnamed mines in the Gubkin subdistrict of the Kursk have wet-magnetic beneficiation plants, one of which also has a flotation circuit. The Kursk districts practical capacity was 15 million tons per year in 1966. Expansion plans and construction projects announced to date do not indicate that capacity will exceed this figure by much in the next few years. The district apparently has typical open pit flexibility of output. There is no reason to believe that mining equipment differs from the 4- to 6-cu yd shovels or truck-rail transport and down-the-hole drills used in the Ukraine.

Olenyogorsk and Kordorsk open pits are the only operating iron mines in the Kola peninsula, or Soviet northwestern iron mining district. The ores are concentrated by magnetic and gravity separation. Total capacity was about 5 million tons of high-grade concentrate in 1966. Plans then were to increase Olenyogorsk's capacity to 12 million tons of crude ore annually and thus add 2.5 million tons of concentrate to the total. At the same time, spiral separators and a flotation circuit were to be added to the beneficiation plant to raise the grade of product above 68 percent iron. Apparently there is little production flexibility. As in the Central European district, it is assumed that the mining equipment is modern and typical of Soviet standards.

Although the Ural Mountain iron ore region is divided into the Northern Ural, Central Ural, and Southern Ural districts, all are in the central and southern part of the Ural Mountain chain from latitude 52° to 60° N.

Mines in the northern Ural district are small open pits and presumably among the worst equipped in the Soviet Union. The ore is cobbed in dry-magnetic separators at the mines, and shipped without further treatment. Total mine capacity in 1966 was 1.3 million tons of crude ore and an estimated 600,000 tons of usable ore annually.

The Gusevogovsk and Pervouralsh open pit and the Vysokogorsk combination open pit-underground mines are the principal producers in the Central Ural District. The Gusevogorsk is part of the Kashnar Mining and Beneficiating Combine (KMBC) that has been under construction since before 1958. KMBC first operated in 1963, with a capacity of 8.5 million tons of crude ore per year and an estimated capacity of 2 million tons of usable ore. The capacity has been increased to an estimated 35 million tons of crude annually. KMBC ore is mined with 4- and 6-cu m shovels loading 90-ton railroad cars. It is concentrated

magnetically in a wet circuit. The concentrate contains recoverable vanadium.

Vysokogorsk produces about 7 million tons per year from two underground shafts, the Magnetitovaya and Exspluatatsionnaya. Underground ore is mined by a modified induced block-caving system. All Vysokogorsk ore is concentrated magnetically.

The Central Ural district had capacity in 1966 to produce 30 million tons of crude ore annually which could be concentrated to an estimated 13 million tons of usable ore.

Magnitnaya Gora, with two open pit mines, is the principal producer in the Southern Ural district. The mines produce high-grade, concentrating, and wash ores. Although a variety of concentrating methods are used, magnetic separation is most often used for the concentrating ores, and washing followed by jigging is used for the other low-grade crudes.

The southern Ural district had capacity in 1966 to produce 1 to 2 million tons of direct shipping ore and about 15 million tons of crude which could be concentrated to 10 million tons of usable ore. Apparently the district produced at its practical capacity because ore was shipped there from other districts.

The iron ore industry of Kazakhstan is in the Turgay iron ore basin in Kustanay territory. Sokolovsko-Sarbayskiy combine, with two open pit mines, was the only producer in the district in 1966. Apparently it is a typical taconite operation except that part of the ore body is relatively high grade. The lower grade ore is concentrated magnetically and pelletized at the mine. Pelletizing was started experimentally in 1965 in the first section of a plant planned to have ten identical sections. The other nine sections may not yet be completed.

The western Siberian iron mining district is in the Altai-Sayan Mountains southeast of the West Siberian Plain. All ore in the district is mined underground in seven relatively small mines. Their total annual capacity is 3.8 million tons of crude, which is concentrated magnetically in a dry circuit to an estimated 3 million tons of usable ore. The district apparently has little excess productive capacity.

The Eastern Siberian Region is in Siberian trap rock in Angaro-Pitsk, South Aldan, and East Transbaikalian provinces. A 4-million-ton-capacity mining and beneficiation combine at Korshunovskoe is the principal iron ore producer. Other operations are not significant.

Asia

India

India's iron ore producers range from small, primitive hand operations to large, modern, well-equipped mines. Relatively few are in the intermediate range. All are open pit, and the majority of the small mines produce from float ore. Approximately 63 percent of the ore is produced in the States of Bihar and Orissa within a 250-mile radius of Calcutta; 18 percent is produced in Madhya Pradesh in an east-west belt in central India; and 18 percent is produced in Mysore in the southwest.

Although India's iron ore industry has increased its output almost tenfold since World War II, the industry as a whole is still in transition to the modern age. Only nine out of more than 200 mines are mechanized, and among these, 4½-cu yd shovels and 27-ton trucks are the largest equipment used. Kiriburu, the largest mine, produces 2 million tons of ore per year, but employs 1,000 men to do so. Some of the ore is crushed and screened, but practically none is concentrated. A few operators tried washing but were unsuccessful. Grade is maintained by hand sorting. Mechanized mines produce excess fines which create both grade and structure problems at the blast furnaces. Under these circumstances the mines do not have typical open pit flexibility of output. Probably the industry is producing at close to its capacity, which is limited by equipment and transportation, not by working faces. There is no apparent barrier to increasing output, except for the personnel problems involved.

Goa

Although Goa now is part of India, its iron ore industry was developed during the time it was a Portuguese colony, and therefore the industry's characteristics are not necessarily the same as those of India. It has about the same preponderance of hand labor, but the mines are individually owned. The industry enjoyed a liberal tax policy under the Portuguese and received preferential treatment on the importation of mining equipemnt and the surrender of exchange earned on exports. Consequently the Goan iron mining industry is fundamentally stronger and its capacity is more evenly distributed in the range of small to large mines than is the industry in other parts of India.

There are about 60 export-oriented mining concerns in Goa. Four of them have capacity to each produce more than 70,000 tons annually, seven can each produce more than 300,000 tons, and one

company operates a 500,000-ton pelletizing plant. Capacity of the others ranges downward to less than 1,000 tons per year.

A large part of the iron ore produced in Goa is man-handled at one point or another, principally in sorting. However, the large mines are mechanized. All are open pit. Ore in the large mines is drilled with jackhammers and wagon drills, and broken with ammonium nitrate and fuel oil explosive mixes. Front-end loaders and power shovels with 2½-cu yd buckets are the largest used. Truck size is limited to 5 tons because the Government has prohibited sizes larger than that on public roads. Goa's iron ore mines have the flexibility that would be expected from the numerous open pit mines, but all the ore is exported through the port of Marmagao, which has limited loading and storage capacity.

Malaysia

The iron mines of Malaysia are all open pit. The Bukit Besi mine in the Dungun area of the State of Trengganu and Bukit Ibam in the Ulu Rompin area of the State of Pahang are the principal producers. Each has capacity of about 3 million tons per year. A dozen or more small intermittent operations produce about 1 million tons per year. Ore is loaded at Bukit Besi and Bukit Ibam by 2- and 5-cu yd shovels into 14- and 35-ton trucks. It is crushed, washed, and screened at both mines, and hauled by narrow-gauge railroad 50 km from Bukit Besi to port and 100 km from Bukit Ibam. The railroads and ship-loading facilities limit mine capacity to some extent, but output could probably be doubled on short notice. Reserves are more significant than mine capacity. Bukit Besi has reserve and grade problems, and if the 1968 rate of production continues, Bukit Ibam soon will begin mining lower grade ores.

Philippines

The Larap open pit underground mine in the Province of Camarines Norte on the Island of Luzon was the only significant iron mine operating in the Philippines in 1968. Its capacity is governed by a magnetic concentrating plant which turns out 750,000 tons of 65 percent iron concentrate per year. Probably the effective capacity under forced draft is more than 1 million tons of concentrate per year. A number of small-scale operators in iron sands of the northern Luzon coast produce 500,000 tons of concentrate annually. It is apparent that the Philippines' iron ore industry will not be significant in international trade unless new deposits are exploited.

Africa

Algeria

The iron ore industry of Algeria was nationalized in the period 1963 to 1966 when difficulties in marketing caused private companies to give up their concessions. The Ouenza Bou Kadra open pit mines, mechanized with rail haulage and operating as a unit, are the only significant operations. They have typical open pit flexibility, but output is restricted by crushing, screening, and blending. Capacity with present equipment is about 3 million tons per year. It could be easily increased.

Angola

The iron ore industry of Angola is centered principally in the Cassinga mine operated by the government-controlled, Companhia Mineira do Lobito. Mining is in open pits which were mechanized in 1966. A 100-ton-per-hour sink-float plant is used to upgrade part of the ore at the Cassinga mine. Capacity is about 3 million tons per year and could be increased fairly rapidly to two or three times that quantity; however, output is governed by the capacity of the railroads that serve the mines.

Liberia

The Liberian iron ore industry is the largest in Africa. Ore is produced in the following four open pit mines, all with government participation:

1. Bomi Hills is owned and operated by the Liberia Mining Co. Ltd., in which Republic Steel Corp. holds a controlling interest. The ore is loaded with 4-yd shovels into 20- and 35-ton trucks. About two-thirds of the ore is processed by magnetic or gravity separation to produce about 1.2 million tons of concentrate per year.

2. Mano River is owned and operated by the National Iron Ore Co., Ltd. Ore is loaded with 2½- and 6-yd shovels into 27-ton trucks. Low grade ore is washed. Capacity is about 5 million tons of 58 percent iron ore concentrates per year.

3. Bong is owned and operated by the German-Liberian Mining Co. The ore is loaded with 6-yd shovels into 45-ton trucks. All is beneficiated with spirals and magnetic separators to produce about 5 million tons of concentrate per year.

4. Mount Nimba is owned by the Liberian American-Swedish Minerals Co. and Liberia Bethlehem Iron Mines Co., but operated by a Gränges (Sweden subsidiary, LAMCO Joint Venture Operating Co.). The ore is loaded with 4- and 6-cu yd shovels into 25- and 35-ton trucks. Production capacity is about 11 million tons per year,

part of which is beneficiated by washing to feed a 2-million-ton-per-year pelletizing plant.

Bomi Hills ore is hauled 43 miles by rail in 50-ton cars to the port at Monrovia. Mano River ore is hauled 50 miles in 60-ton cars to Bomi Hills, and thence to Monrovia over the Bomi Hills line. Bong Iron Range ore is hauled 50 miles in 65-ton cars over a standard gauge line to Monrovia. Mount Nimba ore is hauled 170 miles by rail in 90-ton cars to the port at Lower Buchanan.

Apparently, beneficiation plants and rail capacity limit the open pit mining flexibility of the Liberian iron ore industry. However, output probably could be raised to 25 million tons per year without too much trouble.

Mauritania

Iron ore is produced in Mauritania by the Société Anonyme des Mines de Fer de Mauritanie (MIFERMA) at the Tazadit, Rouessa, and F'Derik open pit mines near Fort Gouraud. The ore, high in grade, is loaded with 6- and 8-cu yd shovels into 27-, 65-, and 110-ton trucks. It is crushed to minus 8 in and transferred by belt conveyor to storage at a railroad loading yard where is is reclaimed with a bucket wheel loader.

The ore is hauled on a standard-gauge railroad 400 miles to Port Étienne. Capacity is about 9 million tons per year, which probably could be increased to twice that amount in a short time.

Morocco

Iron ore is mined in open pits and underground in Morocco by the Government, in the Uixam and Sétolazar mine groups. The ore, mined by room and pillar and sublevel caving underground, is loaded in the open pits by 1½ cu yd shovels into 15-ton trucks. Low grade ore is concentrated by heavy-media and spiral separation methods. Sulfur in pyrite is a problem; part of the ores are roasted to remove it. The properties were acquired by the Government in 1967 to keep the mines operating. Total mine capacity is about 1½ million tons per year, and probably could not be increased much beyond that.

Sierra Leone

Marampa is the only iron mine of significance in Sierra Leone. It is owned and operated by the Sierra Leone Development Co., Ltd. The ore is loaded with 5-cu yd shovels and 25-ton carryalls onto a belt conveyor system terminating at the mill about 400 feet below the mine. There it is washed and concentrated with spirals to about 64 percent iron. The concentrated ore is hauled by narrow gauge railroad 52 miles to the port of Pepal on the Rokell River. Capacity is 2.7 million tons of concentrate per year, which probably could be doubled in a short time.

Republic of South Africa

The iron ore industry of the Republic of South Africa produces principally for internal consumption. The Thabazimbi combination open pit-underground mine and the Sishen open pit mine were the only significant producers until 1966, when the Palabora Mining Co. began producing magnetite concentrate as a byproduct of its copper mining operations in Northwestern Transvaal. Ore is mined in the open pit at Thabazimbi with 2½-cu yd shovels, loading into 8-cu yd railroad cars which transport it along an orepass to crushers in the underground section of the mine. The underground ore is mined by sublevel caving with gathering arm loaders and shuttle cars. Ore at the Sishen open pit is mined with 4½-cu yd shovels loading into 65-ton trucks.

The ore from both mines is concentrated by washing and heavy-media separation. Concentrates are hauled by standard gauge rail to steel mills at Pretoria, Vanderbijlpark, and New Castle. Productive capacity of the two mines is approximately 5 million tons of concentrate per year. Iron ore from the Sishen mine was exported to Japan on a spot purchase basis until 1969 when agreement reportedly was made to supply 1 million tons over a 3-year period to seven Japanese mills.

Oceania

Australia

The iron ore industry of Australia can be divided into two parts, the long-established mines that have produced for internal consumption, and those that have been developed and are being developed to produce ore for the international market.

The established mines are in the Middleback Range and in the Yampi Sound Area of South Australia. The Iron Baron and Iron Prince mines in the Middleback Range are the principal producers. There, the ore is loaded wtih 6-cu yd shovels into 30-ton trucks and transported 30 miles by narrow-gauge railroad to the port at Whyalla. The mines at Yampi Sound are on Koolan and Cockatoo Islands. The ore is mined in open pits with 6-cu yd shovels loading into 45-ton trucks. The trucks take the ore directly to ship loaders at the island ports. Mines in the Middle-

back area have a capacity of 5 million tons annually, and in Yampi Sound Area the mines have a 4-million-ton annual capacity. There is no apparent reason why their capacities could not be increased easily by as much as 50 percent.

The newly developed mines are in Western Australia, the Northern Territory, and Tasmania. Those in Western Australia are the most significant. All are open-pit operations. However, none have yet been completely developed. The Mt. Tom Price mine, 170 miles from the coast, began production in 1966 with 12-cu yd shovels loading 100-ton trucks. The mine produced about 10 million tons in 1968. Eventually, it is expected to produce 37.5 million tons of ore per year, 2 million tons of which is scheduled to be pelletized. The Mt. Newman project, with Mt. Whaleback as the principal mine, 260 miles from the coast, started production in 1969 with 10-cu yd shovels loading 75-ton trucks. Mt. Whaleback had initial capacity to produce 5 million tons per year and projected annual production of over 30 million tons by 1975. The Mt. Goldsworthy mine, 70 miles from the coast, began operating in 1966. Mt. Goldsworthy ore is loaded with 4½-cu yd shovels into 65-ton trucks. The Tallering Peak and Koolanooka ore mines began production in 1966. They are about 100 miles by rail from the port at Geraldton. New railroad and port facilities were constructed to handle the ores from Mt. Whaleback, Mt. Tom Price, and Mt. Goldsworthy. By 1975 the railroad lines and port facilities are scheduled to have the capacity to handle at least 70 million tons of ore or concentrates per year, and equipment for a minimum mine capacity of 75 million tons per year is scheduled to be installed.

Robe River Ltd. will develop deposits near Mount Enid projected to produce shipments of 4.2 million tons of pellets and 6.1 million tons of sintered fines by 1975. A 105-mile rail link and a port at Cape Lambert is planned.

In Tasmania, the Savage River mine capacity is about 2½ million tons of pellets per year. Savage River concentrate is transported in a pipeline 53 miles to Port Latta on the northern coast of Tasmania.

In the Northern Territory, Frances Creek Iron Mining Corp., Pty. Ltd., operation is planned to produce about 1 million tons per year. The ore will be hauled by standard-gauge railroad about 80 miles to the port at Darwin.

IRON ORE CONSUMPTION

Iron ore is used principally for its iron content, and for this purpose it can be consumed in an agglomerating plant or in a smelting furnace. However, as a practical matter, agglomerating plants operated in connection with iron ore mines are not considered points of consumption. There are two reasons for this; first, agglomeration at mines is just one way of beneficiating the ore to make it suitable for market; second, reliable measure of iron ore, in most instances, is obtained only after it is in the form in which it is shipped to market. At smelting plants iron ore used to make agglomerates is considered iron ore consumed because the product is made up of several iron-bearing materials. The product is a mixture and is considered an iron ore only for statistical purposes.

In addition to iron content, impurities and physical characteristics determine the suitability of iron ore for consumption in its several applications. As direct feed for the blast furnace, it is sized and/or blended. All material less than ¼ inch in diameter is removed. The presence of ordinary gangue constituents, silica, alumina, lime, and magnesia, although undesirable, is not cause for rejection if they occur in small quantity. Within limits manganese is a desirable constituent, but phosphorus and sulfur in most instances make iron ore unsuitable for use in smelting furnaces in the United States. High-phosphorus ores are used in European countries where the Thomas process is still used, but these ores are not suitable for use with new steelmaking methods being installed there. Only dense iron ore, either lump or pellet, is suitable for consumption in a steel furnace, because it must penetrate the slag to be effective.

The record of iron-ore consumption in making pig iron in the United States is given in table 12. The ratio between ore consumed and pig iron produced is indicative of the average grade of ore consumed during the year. In the four decades from 1915 to 1955 the ratio provides insight into the economic state of the iron and steel industry during the years. In good years the ratio was high, in poor years it was low. Since 1955 however a steady increase in the average grade of ores consumed was the overriding influence that brought the ratio down from 1.736 in 1955 to 1.579 in 1970. The ratios of iron ore consumption to pig iron and steel production (table 13) show the significance of the steel industry in the market for iron ore. The ratio of pig iron production to crude steel production is an accurate measure of the relationship between primary metal from iron ore and secondary metal from scrap in the steel industry. This can be correlated with year to year economic activity of the steel industry, but con-

Table 12.—Iron ore and other metallic materials consumed in making pig iron, 1915-70

(Thousand long tons)

Year	Materials consumed			Pig iron produced (d)	Ratio, a/d
	Iron ore, manganiferous ore, and agglomerates (a)	Scrap and miscellaneous [1] (b)	Total [2] (c)		
1915	55,157	252	55,409	29,557	1.866
1916	72,065	4,037	76,101	38,702	1.862
1917	69,857	5,648	75,505	37,924	1.842
1918	70,596	5,344	75,940	38,131	1.851
1919	55,471	3,721	59,193	30,508	1.818
1920	65,640	5,650	71,290	36,243	1.811
1921	29,219	2,270	31,489	16,404	1.781
1922	47,396	4,285	51,681	26,826	1.767
1923	71,357	5,376	76,733	39,767	1.794
1924	53,893	4,646	58,540	30,869	1.746
1925	64,368	5,137	69,505	36,125	1.782
1926	68,365	6,255	74,620	38,756	1.764
1927	64,259	5,602	69,861	35,875	1.791
1928	66,421	6,027	72,448	37,411	1.775
1929	75,219	6,817	82,036	41,761	1.801
1930	55,276	4,919	60,195	31,037	1.781
1931	30,518	3,358	33,876	17,953	1.670
1932	13,181	1,955	15,136	8,550	1.542
1933	21,735	2,763	24,498	13,027	1.668
1934	26,488	3,183	29,671	15,686	1.689
1935	35,498	3,304	38,802	20,827	1.704
1936	51,835	4,425	56,260	30,254	1.713
1937	62,676	4,914	67,589	36,145	1.734
1938	32,374	2,572	34,945	18,582	1.742
1939	53,422	4,456	57,879	31,076	1.719
1940	71,740	5,625	77,365	41,254	1.739
1941	84,290	7,300	91,590	49,183	1.714
1942	92,907	6,912	99,818	52,748	1.761
1943	98,037	8,363	106,400	54,255	1.807
1944	97,796	8,258	106,053	54,468	1.795
1945	84,936	7,849	92,785	47,522	1.787
1946	71,805	6,078	77,883	40,038	1.793
1947	93,742	7,795	101,536	52,078	1.800
1948	97,731	7,654	105,385	53,637	1.822
1949	86,650	7,023	93,673	47,610	1.820
1950	104,466	8,516	112,982	57,589	1.814
1951	113,648	9,142	122,790	62,748	1.811
1952	98,365	8,074	106,440	54,740	1.797
1953	118,920	10,164	123,750	66,833	1.779
1954	90,341	7,843	98,184	51,739	1.746
1955	119,087	11,999	131,086	68,615	1.736
1956	115,482	11,797	127,279	66,991	1.724
1957	120,596	11,604	132,200	70,003	1.723
1958	86,346	7,688	94,034	51,031	1.692
1959	89,475	8,176	97,651	53,758	1.664
1960	97,724	8,984	106,708	59,375	1.646
1961	95,044	8,452	103,496	57,904	1.641
1962	94,966	8,986	103,952	58,605	1.620
1963	103,249	9,466	112,715	64,142	1.610
1964	121,145	11,426	132,571	76,301	1.588
1965	124,973	10,744	135,717	78,756	1.587
1966	129,215	9,434	138,649	81,506	1.585
1967	125,718	8,698	134,416	77,498	1.622
1968	127,750	7,970	135,720	79,256	1.611
1969	136,925	8,781	145,706	84,823	1.614
1970	128,702	7,798	136,500	81,512	1.579

[1] Other than revert scrap.

[2] Data may not add to totals shown due to independent rounding.

sidering the significant changes in iron ore technology it has been remarkably stable the last 25 years.

Natural ores and concentrates selected for desirable physical and chemical properties are consumed in cement plants, and are used for pigment purposes. Ores used for heavy aggregate and nuclear shielding have essentially the same characteristics as those consumed in steel furnaces. Only sized, high-grade magnetite concentrate is suitable for consumption as a heavy medium in mineral-dressing plants.

The geographic pattern of iron ore consumption is determined by the location of steel industries. In the United States most of the iron ore is consumed in Pennsylvania, Ohio, Indiana, Illinois, and Michigan, and lesser quantities in New York, Alabama, Utah, Colorado, California, and Texas. Iron ore is consumed in Canada at mills in Ontario near the northern shores of the Great Lakes. It is consumed in Mexico at Monterrey, Puebla, Vera Cruz, and Monclova.

Steel mills in the Brazilian states of Minais Gerais, Rio de Janeiro, and São Paulo consume most of the iron ore in South America. Small steel plants in Argentina, Chile, Peru, and Colombia together consumer 1 to 2 million tons of iron ore per year. An electric smelting plant at Matanzas, Venezuela, consumes another 1 million tons annually.

The European Coal and Steel Community countries, Belgium, Luxembourg, France, West Germany, Italy, and the Netherlands with the United Kingdom consume most of the iron ore in Western Europe. Austria, Spain, and Sweden each consumes 4 to 5 million tons of ore per year, and Yugoslavia accounts for about 2½ million tons. It is significant that the grade of ore consumed in the Community and in the United Kingdom is increasing, the grade of ore consumed in Sweden and Austria is relatively static, and the grade of ore consumed in Spain has been decreasing.

Table 13.—Ratios, total iron ore consumption to pig iron and steel production, 1943-70

Year	Total ore consumption (thousand long tons) (a)	Pig iron production (thousand short tons (b)	Raw crude steel production (thousand short tons) (c)	Ratio, a/b	Ratio, a/c	Ratio, b/c
1943	100,457	60,765	88,837	1.653	1.131	0.684
1944	99,942	61,004	89,642	1.638	1.115	.681
1945	86,158	53,224	79,702	1.619	1.081	.668
1946	72,175	44,842	66,603	1.610	1.084	.673
1947	96,116	58,327	84,894	1.648	1.132	.687
1948	100,499	60,073	86,640	1.673	1.160	.693
1949	89,218	53,323	77,978	1.673	1.144	.684
1950	106,610	64,500	96,836	1.653	1.101	.666
1951	114,837	70,278	105,200	1.634	1.092	.668
1952	100,641	61,308	93,168	1.642	1.080	.658
1953	122,125	74,853	111,610	1.632	1.094	.671
1954	94,229	57,948	88,312	1.626	1.067	.656
1955	125,028	76,849	117,036	1.627	1.068	.657
1956	125,171	75,030	115,216	1.668	1.086	.651
1957	129,375	78,404	112,715	1.650	1.148	.696
1958	91,900	57,155	85,255	1.608	1.078	.670
1959	93,662	60,210	93,446	1.556	1.002	.644
1960	108,050	66,501	99,282	1.625	1.088	.670
1961	99,254	64,853	98,014	1.530	1.013	.662
1962	99,562	65,638	98,328	1.517	1.013	.667
1963	112,535	71,840	109,261	1.566	1.030	.658
1964	132,328	85,458	127,076	1.548	1.041	.672
1965	131,888	88,207	131,462	1.495	1.003	.671
1966	134,047	91,287	134,101	1.468	1.000	.681
1967	127,424	86,799	127,213	1.468	1.002	.682
1968	131,753	88,767	131,462	1.484	1.002	.675
1969	140,235	95,003	141,262	1.476	0.992	.672
1970	131,571	91,293	131,514	1.441	1.000	.694

[1] Includes agglomerates; see table 26.

Japan, China, and India are the principal consumers of iron ore in Asia. Japan's ore is obtained on the open market largely on contracts. The grade and structure is improving. India uses its own ore, mostly high grade. There is no recent specific information on the grade of ore consumed in China, but it is believed to be low, not over 50 percent iron. North Korea consumes 1 to 2 million tons of its own 40- to 50-percent iron ore annually. Consumption in other Asian countries is probably less than 50 thousand tons annually.

The Republic of South Africa is the only significant iron ore-consuming country in Africa. Southern Rhodesia consumes about 500,000 tons per year, and steel industries are just starting in the United Arab Republic and Algeria. Their consumtpion is not yet significant.

The steel industry of Australia consumes around 8 million tons of high-grade iron ore annually. A steel industry based on local iron sands is starting in New Zealand.

TRADE PATTERNS

United States

Trade Patterns

The United States obtains iron ore from mines in Canada, Venezuela, Chile, Liberia, Brazil, and small quantities from Peru and Australia. The iron ore trade with these countries has developed from about 10 million tons valued at $70 million in the early 1950's to over 40 million tons, valued at nearly $500 million, in 1968. The United

States exports iron ore to Canada and Japan. Exports to Canada essentially amount to an exchange across the Great Lakes. The export trade with Japan was developed to help satisfy Japan's need for high-grade ore, but is also one part of a two-way exchange, whereby Japanese ships haul manufactured goods to the United States and return with iron ore for domestic consumption.

U.S. iron ore trade with countries other than Japan and Canada has resulted in little reciprocity.

Table 14.—United States imports of iron ore, 1872-1970

Year	Thousand long tons	Year	Thousand long tons	Year	Thousand long tons
1872 [1]	24	1905	846	1938	2,122
1873	46	1906	1,060	1939	2,413
1874	58	1907	1,229	1940	2,479
1875	57	1908	777	1941	2,344
1876	17	1909	1,695	1942	731
1877	31	1910	2,591	1943	399
1878	28	1911	1,812	1944	464
1879	434	1912	2,105	1945	1,198
1880	493	1913	2,595	1946	2,754
1881	783	1914	1,351	1947	4,896
1882	590	1915	1,341	1948	6,092
1883	491	1916	1,326	1949	7,391
1884	488	1917	972	1950	8,281
1885	391	1918	787	1951	10,140
1886	1,089	1919	476	1952	9,761
1887	1,194	1920	1,273	1953	11,074
1888	587	1921	316	1954	15,792
1889	854	1922	1,135	1955	23,472
1890	1,247	1923	2,768	1956	30,411
1891	913	1924	2,047	1957	33,651
1892	807	1925	2,191	1958	27,544
1893	527	1926	2,555	1959	35,617
1894	167	1927	2,621	1960	34,578
1895	524	1928	2,453	1961	25,805
1896	683	1929	3,139	1962	33,409
1897	490	1930	2,775	1963	33,263
1898	187	1931	1,466	1964	42,408
1899	674	1932	582	1965	45,103
1900	898	1933	861	1966	46,259
1901	967	1934	1,428	1967	44,611
1902	1,165	1935	1,492	1968	43,941
1903	980	1936	2,232	1969	40,758
1904	488	1937	2,442	1970	44,876

[1] First year of record according to Mineral Resources, 1909; American State Papers, and Foreign Commerce and Navigation record values but not quantities for earlier years.

Table 15.—Iron ore imported from Brazil, 1887-1970

Year [1]	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1887	([2])	$4.00	1944	([2])	$5.29
1888-90	--	--	1945	--	--
1891	([2])	5.77	1946	([2])	8.00
1892	([2])	5.00	1947	86	4.93
1893-1918	--	--	1948	296	5.15
1919	([2])	2.00	1949	351	6.50
1920-22	--	--	1950	701	6.75
1923	([2])	3.74	1951	1,038	8.60
1924	([2])	14.84	1952	1,011	14.78
1925	1	11.93	1953	458	13.94
1926	4	14.41	1954	596	11.77
1927	9	7.78	1955	1,011	11.09
1928	32	7.21	1956	1,223	12.61
1929	46	5.63	1957	1,431	14.17
1930	25	16.64	1959	1,200	11.34
1931					
1932	--	--	1960	1,461	10.62
1933	4	4.10	1961	889	10.81
1934-35	--	--	1962	1,299	10.84
1936	6	3.64	1963	781	9.90
1937	11	2.42	1964	1,055	11.05
1938	10	4.58	1965	2,279	10.26
1939	17	4.09	1966	2,723	9.80
1940	99	4.65	1967	1,624	9.08
1941	119	4.03	1968	1,257	9.25
1942	48	3.97	1969	1,233	9.16
1943	--	--	1970	1,991	8.97

[1] Fiscal year before 1918.
[2] Less than 500 tons.

Use Patterns

The historical data showing iron ore consumption in blast furnaces, agglomerating plants, and ferroalloy furnaces accurately reflect the pattern of the principal iron ore uses in the United States. The distinction between iron ore processing in agglomerating plants at mines and iron ore consumption in agglomerating plants at steel mills is discussed under Iron Ore Consumption above. Iron ore concentration is expanding the application of agglomeration at the mines. Iron ore agglomeration at the steel mills, mostly in the form of sintering, is on the downtrend in relation to overall consumption, because iron ore agglomerates in the form of pellets are taking the place of iron ore and iron ore concentrates, and because of less fine-grained material is reaching the mills.

Table 16.—Iron ore imported from Canada [1, 2] 1884-1970

Year [3]	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1884	29	$2.47	1928	50	$3.86
1885	50	3.50	1929	80	4.15
1886	8	3.18	1930	49	4.16
1887	28	2.79	1931	24	3.39
1888	14	3.01	1932	1	3.20
1889	28	2.44	1933	([4])	3.51
1890	30	2.73	1934	11	5.08
1891	21	2.58	1935	20	5.43
1892	6	2.47	1936	95	4.64
1893	9	3.13	1937	50	3.19
1894	([4])	2.81	1938	1	30.22
1895	2	4.22	1939	37	4.52
1896	([4])	4.06	1940	245	4.57
1897	29	1.11	1941	314	4.16
1898	25	1.08	1942	256	4.47
1899	2	2.22	1943	279	4.40
1900	126	1.01	1944	255	4.67
1901	145	1.33	1945	704	3.72
1902	349	2.18	1946	1,110	4.62
1903	222	1.86	1947	1,540	4.90
1904	178	1.96	1948	969	5.97
1905	113	2.23	1949	1,616	6.65
1906	138	1.86	1950	1,853	6.87
1907	149	1.15	1951	1,962	7.34
1908	102	1.34	1952	1,822	7.62
1909	95	1.22	1953	1,841	8.72
1910	281	1.72	1954	3,537	8.09
1911	280	1.97	1955	10,077	7.85
1912	252	1.66	1956	13,723	8.57
1913	393	1.87	1957	12,537	8.92
1914	91	2.32	1958	8,289	9.33
1915	84	2.91	1959	13,458	9.58
1916	137	3.72	1960	10,595	9.88
1917	196	4.35	1961	9,683	10.24
1918	115	5.30	1962	16,825	10.09
1919	12	5.23	1963	18,891	10.56
1920	34	4.82	1964	24,854	11.05
1921	4	3.72	1965	23,756	11.13
1922	3	3.68	1966	23,941	11.42
1923	58	3.76	1967	24,214	11.42
1924	4	3.81	1968	26,339	11.69
1925	8	2.75	1969	19,004	11.56
1926	137	3.77	1970	23,919	12.42
1927	87	3.86			

[1] Includes Newfoundland and Labrador.
[2] Before 1884 not available.
[3] Fiscal year before 1918; 157,919 tons received in last 6 months of 1917.
[4] Less than 500 tons.

Table 17.—Iron ore imported from Chile, 1914-1970

Year	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1914	35	$1.19	1944	--	--
1915	154	1.18	1945	215	1.80
1916	62	1.19	1946	1,096	2.25
1917-20	--	--	1947	1,662	2.81
1921	8	3.75	1948	2,632	2.86
1922	260	6.26	1949	2,677	2.62
1923	635	5.84	1950	2,607	2.62
1924	1,145	6.53	1951	2,767	3.10
1925	1,114	2.89	1952	1,862	4.43
1926	1,364	1.14	1953	2,363	5.22
1927	1,369	1.14	1954	1,664	4.73
1928	1,435	1.10	1955	1,035	5.20
1929	1,699	1.45	1956	1,564	6.91
1930	1,689	2.40	1957	2,741	7.53
1931	751	2.42	1958	3,257	7.94
1932	218	2.37	1959	3,590	7.75
1933	468	2.01	1960	3,942	7.78
1934	938	2.04	1961	2,604	8.42
1935	789	1.85	1962	3,400	8.50
1936	1,264	1.81	1963	2,679	9.46
1937	1,439	1.81	1964	2,712	8.93
1938	1,578	1.81	1965	2,660	8.74
1939	1,587	1.78	1966	2,268	8.73
1940	1,683	1.80	1967	1,365	8.27
1941	1,686	1.82	1968	1,441	7.99
1942	383	1.80	1969	1,783	8.06
1943	--	--	1970	1,581	8.10

Table 18.—Iron ore imported from Liberia, 1950-70

Year	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1950	([1])	--	1961	715	$9.41
1951	110	$5.03	1962	757	8.56
1952	572	5.52	1963	1,310	7.59
1953	710	8.12	1964	2,873	7.06
1954	764	8.25	1965	2,813	7.10
1955	928	7.60	1966	3,390	7.33
1956	1,218	9.13	1967	3,099	7.66
1957	1,013	9.66	1968	2,942	7.95
1958	18,371	8.47	1969	3,144	8.66
1959	1,105	9.34	1970	1,873	9.19
1960	907	8.86			

[1] Less than 1 ton.

Table 19.—Iron ore imported from Peru, 1953-70

Year	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1953	844	$7.06	1962	573	$10.81
1954	1,932	8.07	1963	290	8.30
1955	1,559	8.78	1964	580	11.46
1956	1,840	8.92	1965	957	10.82
1957	2,373	8.79	1966	1,043	10.82
1958	1,674	10.03	1967	879	10.70
1959	2,236	9.55	1968	925	10.14
1960	2,758	9.73	1969	1,003	10.71
1961	1,209	9.72	1970	1,329	10.36

Table 20.—Iron ore imported from Venezuela, 1887-1970

Year [1]	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1887	2	$1.79	1952	1,846	$7.92
1888	2	1.01	1953	1,950	8.73
1889-90	--	--	1954	5,210	6.92
1891	([2])	2.00	1955	7,160	6.36
1892-97	--	--	1956	9,254	6.69
1898	1	3.25	1957	12,291	7.14
1899	--	--	1958	12,180	7.22
1900	1	2.32	1959	13,542	7.71
1901-11	--	--	1960	14,555	9.15
1912	2	5.12	1961	10,478	9.46
1913	30	4.69	1962	10,328	9.39
1914	40	3.30	1963	9,231	8.33
1915-21	--	--	1964	9,954	7.96
1922	1	4.17	1965	12,273	7.98
1923-28	--	--	1966	12,592	8.10
1929	([2])	19.00	1967	12,820	8.09
1930-31	--	--	1968	10,313	8.06
1932	([2])	20.00	1969	13,751	8.05
1933-50	--	--	1970	13,026	8.33
1951	635	5.95			

[1] Fiscal year before 1918.
[2] Less than 500 tons.

Table 21.—Iron ore imported from Sweden, 1889-1970

Year [1]	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1889 [2]	3	$3.87	1934	41	$4.99
1890-92	--	--	1935	58	5.01
1893 [2]	1	3.74	1936	166	4.08
1894-1900	--	--	1937	150	5.30
1901 [2]	([3])	4.00	1938	214	6.27
1902-06	--	--	1939	264	4.64
1907 [2]	4	3.41	1940	211	4.60
1908	5	3.42	1941-45	--	--
1909	6	5.50	1946	233	5.95
1910	189	5.21	1947	1,287	6.03
1911	298	5.48	1948	1,359	6.12
1912	325	5.41	1949	2,027	6.36
1913	275	5.31	1950	2,047	6.60
1914	367	5.30	1951	2,522	6.71
1915	202	5.25	1952	2,111	11.61
1916	224	5.20	1953	2,098	12.97
1917	148	5.27	1954	1,544	9.22
1918	--	--	1955	1,221	10.10
1919	62	6.24	1956	999	11.92
1920	64	5.33	1957	677	14.14
1921	143	2.68	1958	113	14.51
1922	318	3.32	1959	136	12.77
1923	750	3.60	1960	94	16.40
1924	318	3.38	1961	78	14.82
1925	149	3.73	1962	32	17.68
1926	54	4.01	1963	37	20.05
1927	244	3.73	1964	93	11.92
1928	27	4.06	1965	57	19.43
1929	310	3.94	1966	82	18.57
1930	203	4.70	1967	148	12.43
1931	84	4.09	1968	232	11.25
1932	7	3.97	1969	155	10.70
1933	([3])	5.00	1970	172	11.10

[1] Fiscal year prior to 1918; 17,718 tons received in last 6 months of 1917.
[2] Includes Norway.
[3] Less than 500 tons.

The use of iron ore in steel furnaces is gradually declining as more steel is produced in electric and oxygen steelmaking furnaces. The use of iron ore in ferroalloy furnaces fluctuates from year to year, because few furnaces are used solely to produce feroalloys. Therefore, in many instances feroalloys produced in 1 year are used in the next.

Magnetite is used as heavy media in iron ore concentration plants and in coal-washing plants. However, ferrosilicon has replaced the magnetite to a large extent.

Table 22.—U.S. exports of iron ore, 1880-1970

Year [1]	Thousand long tons	Year	Thousand long tons	Year	Thousand long tons
1880 [2]	1	1913	1,221	1942	2,515
1881	4	1914	1,005	1943	2,425
1882	5	1915	407	1944	2,158
1883	1	1916	924	1945	2,063
1884	3	1917	1,025	1946	1,506
1885	3	1918	1,256	1947	2,811
1886	1	1919	997	1948	3,081
1887	3	1920	1,145	1949	2,425
1888	2	1921	440	1950	2,551
1889	--	1922	602	1951	4,329
1890-94	--	1923	1,117	1952	5,123
1895	1	1924	595	1953	4,251
1896	1	1925	631	1954	3,146
1897	10	1926	869	1955	4,517
1898	12	1927	899	1956	5,508
1899	31	1928	1,282	1957	5,002
1900	41	1929	1,304	1958	3,573
1901	61	1930	752	1959	2,967
1902	68	1931	436	1960	5,273
1903	77	1932	83	1961	4,958
1904	83	1933	155	1962	5,898
1905	262	1934	609	1963	6,812
1906	227	1935	661	1964	6,963
1907	238	1936	645	1965	7,085
1908	293	1937	1,264	1966	7,779
1909	402	1938	592	1967	5,906
1910	544	1939	1,057	1968	5,884
1911	738	1940	1,386	1969	5,160
1912	832	1941	1,908	1970	5,492

[1] Fiscal year before 1918; 936,607 tons exported in last 6 months of 1917.

[2] American State Papers and Foreign Commerce and Navigation record values but not quantities for earlier years.

Table 23.—Iron ore exported to Canada,[1] 1884-1970

Year [2]	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1884	3	$2.94	1930	752	$3.63
1885	3	2.81	1931	436	3.80
1886	1	2.00	1932	83	2.63
1887	3	2.03	1933	155	4.16
1888	2	2.05	1934	609	3.68
1889-95	--	--	1935	661	2.90
1896	1	3.56	1936	637	3.00
1897	10	3.50	1937	1,264	3.20
1898	12	2.97	1938	591	3.30
1899	30	2.02	1939	1,033	3.38
1900	40	1.94	1940	1,386	3.34
1901	61	2.89	1941	1,907	3.26
1902	68	2.61	1942	2,515	3.23
1903	77	3.44	1943	2,425	3.35
1904	83	3.05	1944	2,158	3.32
1905	236	2.24	1945	2,063	3.24
1906	227	2.68	1946	1,506	3.64
1907	238	2.82	1947	2,811	3.56
1908	293	3.01	1948	3,020	4.37
1909	402	3.15	1949	2,169	5.68
1910	544	3.01	1950	2,551	6.16
1911	738	3.38	1951	3,340	6.51
1912	832	3.37	1952	3,790	6.47
1913	1,221	3.02	1953	3,854	7.29
1914	1,005	3.39	1954	2,813	7.70
1915	407	3.14	1955	4,232	8.05
1916	923	3.02	1956	4,529	8.67
1917	1,025	3.20	1957	3,958	9.32
1918	1,256	4.41	1958	3,077	9.65
1919	997	4.32	1959	2,453	11.49
1920	1,141	5.41	1960	4,428	11.06
1921	438	4.72	1961	3,889	10.87
1922	596	4.60	1962	4,781	10.75
1923	1,117	4.75	1963	4,987	11.64
1924	595	4.04	1964	4,834	12.12
1925	630	3.82	1965	4,560	11.93
1926	869	3.89	1966	3,911	12.42
1927	887	3.80	1967	2,258	12.87
1928	1,250	3.72	1968	2,278	12.34
1929	1,295	3.66	1969	2,085	12.08
--	--	--	1970	2,045	13.26

[1] Before 1884 not available.

[2] Fiscal year before 1918; 933,729 tons exported in last 6 months of 1917.

Table 24.—Consumption of iron ore and agglomerates in the United States, 1943-1970

(Thousand long tons)

Year	Metallurgical uses				Miscellaneous uses			Total [1]
	Iron blast furnaces	Steel furnaces	Sintering plants	Ferroalloy furnaces	Cement	Paint	Other	
1943	85,256	4,126	10,363	528	7	26	150	100,457
1944	82,812	4,144	12,248	412	82	10	234	99,942
1945	71,318	3,409	10,836	400	80	10	106	86,158
1946	60,461	3,182	8,066	249	138	54	24	72,175
1947	78,864	4,112	12,529	329	167	103	12	96,116
1948	82,376	4,351	13,091	346	213	111	10	100,499
1949	72,965	3,804	11,869	239	208	80	54	89,218
1950	86,921	4,728	14,276	248	231	115	91	106,610
1951	91,649	5,486	16,796	425	249	113	121	114,837
1952	78,982	5,167	15,694	388	243	110	56	100,641
1953	93,802	6,819	20,727	368	224	90	95	122,125
1954	68,542	5,590	18,149	305	218	87	1,338	94,229
1955	94,811	7,114	22,365	300	256	103	77	125,028
1956	89,163	7,270	27,903	442	262	32	97	125,171
1957	87,424	7,525	33,763	265	258	26	115	129,375
1958	52,474	6,101	32,464	159	255	13	434	91,900
1959	49,036	6,186	37,263	318	329	19	510	93,662
1960	45,995	6,601	[2] 54,461	221	361	48	363	108,050

Year [3]	Iron blast furnaces		Steel furnaces		Miscellaneous uses [5]	Total [1]
	Iron ore [4]	Agglomerate	Iron ore [4]	Agglomerate		
1961	39,767	55,613	6,420	764	465	103,029
1962	37,421	56,619	5,931	1,050	848	101,869
1963	60,939	44,343	6,667	64	522	112,535
1964	74,751	48,969	7,325	648	635	132,328
1965	69,498	55,058	5,985	887	460	131,888
1966	70,753	56,701	4,956	980	657	134,047
1967	68,028	54,613	3,707	611	466	127,424
1968	74,176	58,097	3,452	560	468	131,753
1969	83,174	53,182	2,715	704	460	140,235
1970	81,240	50,367	2,339	635	479	135,000

[1] Data may not add to totals shown due to independent rounding.

[2] Sintering changed to agglomerating in 1960.

[3] Change in reporting iron ore from amount consumed in agglomerating plants to actual furnace consumption is reflected in totals from 1961-69.

[4] Not agglomerated.

[5] Includes iron ore used in making paint and cement, and consumed in ferroalloy furnaces.

Table 25.—Iron ore exported to Japan, 1932-70

Year	Thousand long tons	Average value per ton	Year	Thousand long tons	Average value per ton
1932	(1)	$2.63	1955	285	$10.08
1933	--	--	1956	974	9.56
1934	(1)	3.68	1957	1,041	10.12
1935	--	--	1958	493	10.23
1936	3	10.80	1959	507	10.35
1937	(1)	18.58	1960	839	10.28
1938	(1)	5.69	1961	883	10.93
1939-47	--	--	1962	981	10.41
1948	61	8.97	1963	1,682	10.16
1949	252	9.11	1964	2,021	10.02
1950	--	--	1965	2,431	10.46
1951	988	9.36	1966	3,778	11.35
1952	1,332	9.67	1967	3,602	11.71
1953	398	10.85	1968	3,550	11.92
1954	332	9.23	1969	3,009	11.81
--	--	--	1970	3,206	11.77

[1] Less than 500 tons.

Table 26.—Consumption of iron ore and agglomerates in the United States, 1961-70

(Thousand long tons)

Year	Iron blast furnaces: Iron ore[1]	Iron blast furnaces: Agglomerate	Steel furnaces: Iron ore[1]	Steel furnaces: Agglomerate	Steel furnaces: Miscellaneous uses[2]	Total[3]
1961[4]	39,767	55,613	6,420	764	465	103,029
1962	37,421	56,619	5,931	1,050	848	101,869
1963	60,939	44,343	6,667	64	522	112,535
1964	74,751	48,969	7,325	648	635	132,328
1965	69,498	55,058	5,985	887	460	131,888
1966	70,753	56,701	4,956	980	657	134,047
1967	68,028	54,613	3,707	611	466	127,424
1968	74,176	53,097	3,452	560	468	131,753
1969	83,174	53,182	2,715	704	460	140,235
1970	77,811	50,367	2,339	635	419	131,571

[1] Includes pellets and modules produced at mines.

[2] Includes iron ore used in making paint and cement, and consumed in ferroalloy furnaces.

[3] Data may not add to totals shown because of independent roundings.

[4] Change in reporting iron ore from amount consumed in agglomerating plants to actual furnace consumption is reflected in totals from 1961-70.

Table 27.—Iron ore supply balance, 1943-70

(Thousand long tons)

Year	Total beginning stocks	Domestic shipments[1]	Imports	Exports	Total end stocks	Apparent consumption	Reported consumption	Less adjustment for agglomerates[2]	Difference
1943	50,954	99,463	399	2,425	49,716	98,675	100,457	——	+1,782
1944	49,716	95,136	464	2,158	41,993	101,165	99,942	——	—1,222
1945	41,993	88,137	1,198	2,063	43,473	85,791	86,158	——	— 368
1946	43,473	70,090	2,754	1,506	43,410	71,402	72,175	——	+ 772
1947	43,410	93,315	4,896	2,811	43,866	94,943	96,116	——	+1,172
1948	43,866	100,822	6,092	3,081	48,333	99,365	100,499	——	+1,133
1949	48,333	84,687	7,391	2,425	48,442	89,545	89,218	——	— 326
1950	48,442	97,764	8,281	2,551	46,042	105,895	106,610	——	+ 715
1951	46,042	116,230	10,140	4,329	52,948	115,134	114,837	——	— 297
1952	52,948	97,973	9,761	5,123	54,775	100,785	100,641	——	— 144
1953	54,775	117,822	11,074	4,251	58,619	120,801	122,125	——	+1,324
1954	58,619	76,954	15,792	3,146	56,808	91,411	94,229	——	+2,818
1955	56,808	106,258	23,472	4,517	53,557	128,464	125,028	——	—3,436
1956	53,557	97,924	30,411	5,508	57,315	119,069	125,171	——	+6,102
1957	57,315	104,970	33,651	5,002	65,111	125,823	129,375	——	3,552+
1958	65,111	66,959	27,544	3,573	66,209	89,832	91,900	——	+2,068
1959	66,209	59,855	35,617	2,967	67,971	90,743	93,662	——	+2,919
1960	67,971	83,784	34,578	5,273	80,745	100,315	108,050	——	+7,735
1961	80,745	72,949	25,805	4,958	75,304	99,237	99,254	——	+ 17
1962	75,304	70,410	33,409	5,898	77,596	95,629	101,869	4,288	+1,952
1963	77,596	74,387	33,263	6,812	71,417	107,017	112,535	4,837	+ 681
1964	71,417	85,184	42,408	6,963	68,171	123,929	132,328	5,052	+3,247
1965	68,171	85,441	45,103	7,085	68,960	122,560	131,888	5,064	+4,264
1966	68,960	90,824	46,259	7,779	69,525	128,739	134,047	6,659	—1,351
1967	69,525	83,016	44,611	5,906	71,067	120,179	127,424	7,203	+ 42
1968	71,067	82,531	43,941	5,884	72,070	119,585	131,753	11,883	+ 284
1969	72,070	90,581	40,758	5,160	67,441	130,808	140,235	8,202	+1,225
1970	67,441	87,891	44,876	5,492	71,500	123,216	131,571	6,552	+1,803

[1] Includes byproduct ore.

[2] Difference largely due to materials other than iron ore added during production of agglomerate.

Iron Ore Supply Balance .

The historical iron ore supply balance in which apparent consumption is compared with reported consumption is given in table 27. Inasmuch as the time of measurement is not identical among producing and consuming operations, and there is always a substantial quantity of iron ore in transit, slight variation between apparent and reported iron ore consumption is to be expected. However, it is noteworthy that reported consumption exceeded apparent consumption by 2 to 7 percent in the period 1954 to 1960. This discrepancy was caused by erroneously measuring iron ore consumption at agglomerating plants connected with mines. Measuring all ore in the form shipped to consuming plants, whether direct shipping, concentrate, or agglomerate, has brought the U.S. supply into a more reasonable balance with consumption since 1960.

World

Trade Patterns

World trade in iron ore almost quadrupled in the 15 years prior to 1965—from 55 million tons in 1951 to 210 million tons in 1965. Since the major consuming centers are in the northern hemisphere, the principal flow is from south to north. The ore follows traditional trade routes, the principal exception being that ore moving from Australia, South American countries, and the Republic of South Africa to Japan. A map showing the flow of iron ore between the principal producing and consuming countries in 1966, the latest year for which data are available, is shown in fig. 15.

World Exports

Western Hemisphere countries exporting iron ore had 40 percent of the world's export trade in 1965, African countries had 14 percent, and Asian countries, 9 percent. Canada, the U.S.S.R., and Liberia stand out among countries that have greatly increased their iron ore export trade since 1950. On the other hand, France had one-fourth of the world's export trade in iron ore in 1950, but had dropped to less than 10 percent by 1965.

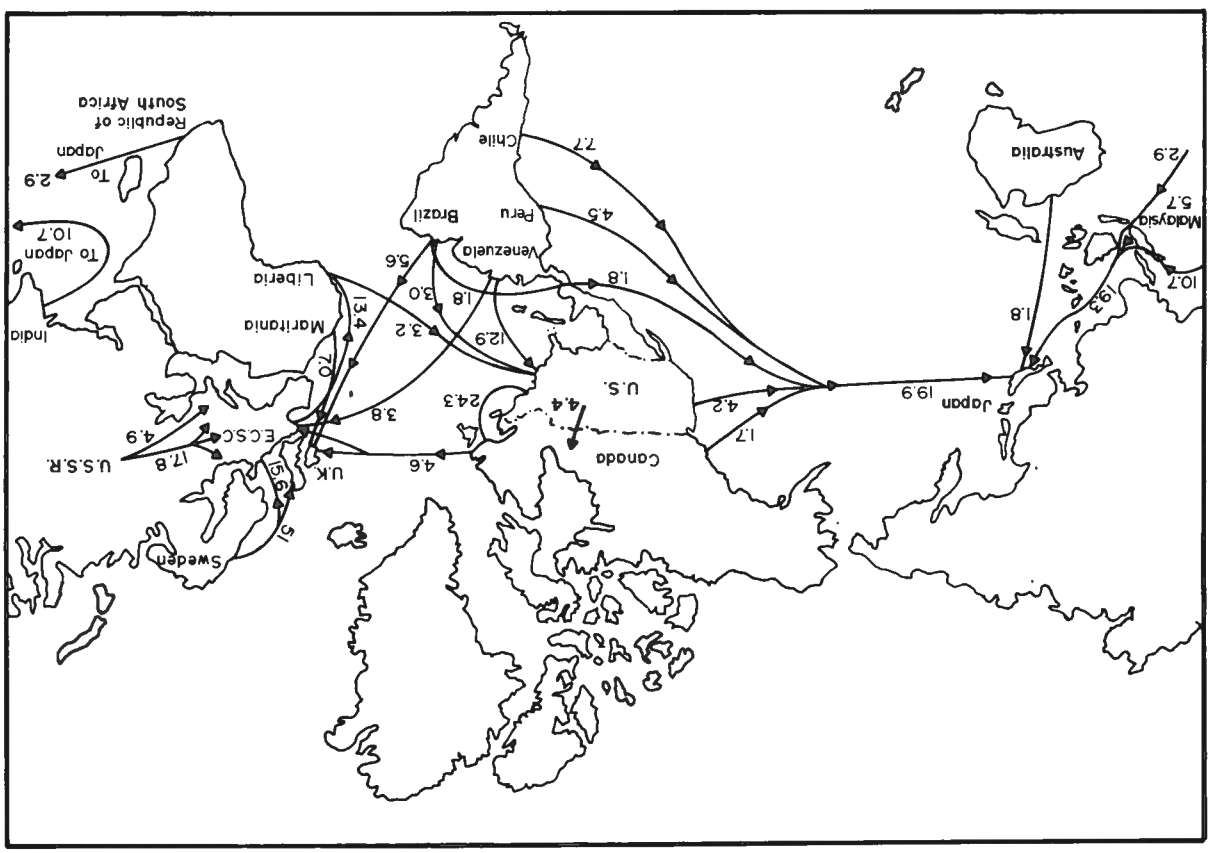

FIGURE 15.—Flow of iron ore between principal producing and consuming countries of the world (1966).

Table 28.—Iron ore exp

(Tho

	North America		South America				Europe			
	Canada	United States	Brazil	Chile	Peru	Venezuela	France	Norway	Spain	
1951	2,926	4,398	1,320	2,687	--	646	15,832	269	1,550	14,
1952	3,436	5,123	1,537	1,798	--	1,859	15,685	,700	1,778	15,
1953	4,304	4,252	1,523	2,403	933	1,942	16,115	893	1,446	14,
1954	5,470	3,146	1,652	1,694	1,151	5,419	17,091	896	1,160	13,
1955	13,008	4,517	2,525	1,218	1,711	8,305	20,751	1,164	2,102	15,
Total	29,144	21,436	8,557	9,800	3,795	18,171	85,474	3,922	8,036	73,
Percent of total	8.6	6.3	2.5	2.9	1.1	5.3	25.2	1.2	2.4	2
1956	18,094	5,508	2,702	2,039	2,631	11,163	21,298	1,242	3,207	17,
1957	17,973	5,002	3,481	3,005	3,619	15,215	22,070	1,224	3,408	17,
1958	12,391	3,385	2,779	3,581	2,470	15,325	23,084	1,140	2,122	14,
1959	18,552	2,967	3,895	4,193	3,267	17,104	27,502	925	1,769	15,
1960	16,942	5,236	5,079	5,109	5,111	19,271	26,726	1,173	2,516	19,
Total	83,952	22,098	17,936	17,927	17,098	78,078	120,680	5,704	13,022	83,
Percent of total	13.2	3.5	2.8	2.8	2.7	12.3	19.1	0.9	2.1	1
1961	14,868	4,958	6,138	6,634	5,506	14,335	25,446	1,124	2,070	19,
1962	21,646	5,897	7,529	7,184	5,068	13,100	25,278	1,248	1,874	19,
1963	23,855	6,809	8,137	6,980	5,647	12,158	20,869	1,203	1,959	19,
1964	30,474	6,963	9,576	8,969	5,123	14,658	21,742	1,528	2,414	23,
1965	30,799	7,085	12,530	10,560	6,274	16,737	20,420	1,422	1,916	24,
Total	121,642	31,712	43,910	40,327	27,618	70,988	113,755	6,525	10,233	107,
Percent of total	14.0	3.6	5.0	4.6	3.2	8.2	13.1	0.8	1.2	1
1966	30,694	8,712	12,706	10,913	6,208	16,768	17,907	1,481	1,014	22,

principal exporting countries

g tons)

	Asia						Africa				Oceana		
U.S.S.R.	India and Goa	Malaysia	Philippines	Algeria	Angola	Liberia	Mauritania	Morocco	Sierra Leone	Republic of South Africa	Australia	Other	TOTAL
--	485	793	938	2,842	--	--	--	1,513	1,204	--	--	2,306	54,701
--	1,133	1,008	1,203	3,074	--	877	--	1,566	1,379	--	--	2,655	60,277
--	1,943	1,019	1,187	3,199	--	1,434	--	1,410	1,200	4	--	3,289	62,819
--	2,179	1,060	1,276	2,824	--	1,238	--	1,100	877	--	--	2,337	64,430
8,661	2,711	1,592	1,401	3,568	--	1,716	--	1,286	1,332	4	--	4,219	97,198
8,661	8,451	5,472	6,005	15,507	--	5,265	--	6,875	5,992	8	--	14,806	339,375
2.5	2.5	1.6	1.8	4.6	--	1.5	--	2.0	1.8	--	--	4.1	
8,980	3,734	2,376	1,501	2,451	--	2,027	--	1,812	1,328	28	--	5,064	114,217
0,603	4,841	2,920	1,287	2,702	--	2,129	--	1,908	1,487	10	--	5,572	125,647
1,731	4,325	2,591	1,024	2,287	219	2,035	--	1,279	1,422	8	--	3,984	111,758
3,234	6,148	3,748	1,178	1,991	332	2,665	--	695	1,503	166	--	3,428	130,486
4,942	9,000	5,500	1,132	3,517	537	2,916	--	798	1,541	467	--	4,509	151,428
9,490	28,048	17,135	6,122	12,948	1,088	11,772	--	6,492	7,281	679	--	22,557	633,536
9.4	4.4	2.7	1.0	2.0	0.2	1.9	--	1.0	1.1	0.1	--	3.5	
6,026	9,920	6,435	1,289	2,737	487	2,792	--	1,879	1,758	558	--	3,922	148,812
8,636	8,585	6,441	1,314	2,098	439	2,844	--	1,130	1,983	732	--	4,491	156,607
0,461	7,789	6,582	1,442	1,928	645	6,453	1,230	1,063	1,954	680	--	3,400	161,179
2,243	10,316	6,317	1,491	2,784	1,110	12,069	4,888	978	1,980	1,068	--	4,264	194,914
3,757	11,086	6,634	1,357	2,945	682	15,421	5,871	942	2,297	2,195	97	4,602	210,121
1,123	47,696	32,409	6,893	12,492	3,363	39,579	11,989	5,991	9,972	5,233	97	20,679	871,633
11.6	5.5	3.7	0.8	1.4	0.4	4.5	1.4	0.7	1.1	0.6	--	2.3	
5,705	13,442	5,681	1,575	1,581	617	16,556	7,022	777	2,183	3,040	1,964	4,073	212,807

Table 29.—Iron ore imports of principal consuming countries measured by exports to country of destination

(Thousand of long tons)

	North America		South America	Europe												Asia			
	Canada	United States	Argentina	Austria	Belgium-Luxembourg	Czechoslovakia	France	Germany, East	Germany, West	Hungary	Italy	Netherlands	Poland	Rumania	United Kingdom	Other Europe	Japan	Other Countries	TOTAL
1951	3,518	9,900	--	--	11,372	--	--	--	6,677	--	--	--	--	--	8,932	10,944	3,354	4	54,701
1952	3,906	9,711	--	485	10,991	519	392	--	9,360	--	664	1,510	1,186	--	9,520	6,790	4,929	264	60,227
1953	3,988	11,121	--	338	11,533	465	889	--	9,681	--	783	1,514	1,035	--	10,452	6,667	4,237	115	62,818
1954	2,930	14,944	--	242	12,468	580	257	--	8,496	--	618	1,118	846	--	10,787	6,742	4,235	167	64,430
1955	4,341	24,522	--	816	15,010	3,147	501	--	13,639	--	1,037	1,513	4,380	--	12,714	7,829	4,925	2,824	97,198
Total	18,683	70,198	--	1,881	61,374	4,711	2,039	--	47,853	--	3,102	5,655	7,447	--	52,405	38,972	21,680	3,374	339,374
Percent of total	5.6	20.5	--	0.5	18.1	1.4	0.6	--	14.1	--	0.9	1.7	2.2	--	15.5	11.5	6.4	1.0	100
1956	4,635	30,982	--	929	15,534	3,524	625	1,274	16,813	--	1,389	1,286	4,649	--	14,227	8,147	7,851	2,352	114,217
1957	4,196	33,571	--	1,026	15,644	4,409	1,075	1,527	18,763	1,254	2,229	1,307	5,485	--	15,957	8,185	8,826	2,193	125,647
1958	2,948	28,086	--	997	16,605	4,634	947	1,743	16,045	1,754	1,959	1,563	5,361	705	12,392	8,043	7,090	886	111,758
1959	2,707	35,724	--	677	17,883	5,853	995	1,991	20,120	1,629	1,878	2,045	5,645	812	12,879	7,816	10,526	1,306	130,486
1960	4,609	34,264	--	1,521	20,433	6,524	1,426	2,123	32,727	1,793	2,743	2,125	6,621	1,056	17,440	334	14,967	722	151,428
Total	19,095	162,627	--	5,150	86,099	24,944	5,068	8,658	104,468	6,430	10,198	8,326	27,761	2,573	72,895	32,525	49,260	7,459	633,536
Percent of total	3.0	25.7	--	0.8	13.6	3.9	0.8	1.4	16.5	1.0	1.6	1.3	4.4	0.4	11.5	5.1	7.8	1.2	100
1961	4,173	26,007	--	1,255	20,201	7,247	1,664	2,036	32,751	1,920	3,378	2,117	7,461	1,247	14,434	1,076	21,065	780	148,812
1962	5,093	33,067	646	980	20,711	8,003	1,844	2,533	28,331	2,165	4,535	1,905	8,266	1,888	12,366	1,598	21,631	1,045	156,607
1963	5,422	32,637	568	973	19,192	8,938	3,441	2,471	26,220	2,278	4,804	2,296	8,434	2,140	14,666	1,278	24,392	1,029	161,179
1964	5,207	42,200	1,036	1,056	22,613	9,017	3,595	2,614	35,115	2,523	5,131	3,393	8,903	2,288	18,017	1,913	29,352	91	194,914
1965	4,959	44,965	1,139	1,137	23,469	9,271	3,799	2,656	35,160	2,407	8,012	3,575	8,998	2,562	18,429	3,222	35,809	552	210,121
Total	24,854	178,876	3,389	5,401	106,186	42,476	14,343	12,310	157,577	11,293	25,860	13,286	42,062	10,075	77,912	9,087	132,249	4,397	871,633
Percent of total	2.8	20.5	0.4	0.6	12.2	4.9	1.7	1.4	18.1	1.3	3.0	1.5	4.8	1.2	8.9	1.0	15.2	0.5	100
15-year Total (1951-1965)	62,632	411,701	3,389	12,432	253,659	72,131	21,450	20,968	309,898	17,723	39,160	27,267	77,270	12,648	203,212	80,584	208,189	15,230	1,838,533
Percent of total	3.4	22.4	0.2	0.7	13.8	3.9	1.2	1.1	16.8	1.0	2.1	1.5	4.2	0.7	11.0	4.4	11.1	0.8	[1] 100
1966	4,782	46,744	887	1,072	21,019	9,155	4,201	2,747	31,053	2,626	7,729	3,694	9,391	2,807	15,609	3,582	45,275	434	212,807

[1] Percentage totals may not add to 100 because of independent rounding.

For that period, exports from Spain, the Philippines, and Algeria have fallen behind the growth rate of the remainder of the world. It is noteworthy that the iron ore industries of these countries have not met quality competition, although their costs have consistently been less than the costs of their competitors.

World Imports

The countries of Western Europe and the United Kingdom continue to dominate the import side of world trade in iron ore. They accounted for more than 45 percent of the total in 1965. Japan has greatly outpaced other countries of the world in its growth rate in the iron ore trade. In the first half of the 1950's Japan accounted for only 6 percent of total imports, while the United States accounted for 21 percent. By 1965, Japan accounted for 17 percent of the total and the United States had increased its share to only 22 percent, despite the phenomenal rate of growth of its iron ore production.

CHAPTER 6.—STRUCTURE OF THE INDUSTRY

IRON ORE PRODUCING INDUSTRY OF THE UNITED STATES

The iron mining industry of the United States is discussed in four groups or districts: Lake Superior, Southeastern States, Northeastern States, and Western States. As noted in the previous chapter, only the Lake Superior district is a mining district; here the ore deposits occur in similar geologic formations and are genetically related. Other districts are geographic groupings of mines used to facilitate statistical reporting.

Lake Superior district mines are grouped in the Mesabi, Vermilion, and Cuyuna Ranges in Minnesota, the Gogebic, Marquette, and Menominee Ranges in Michigan, and the Gogebic Range in Wisconsin. These Ranges are recognized geologic structures.

Mines in the Clinton Formation that serve the Birmingham steel district form the core of the Southeastern States district. However, mining has all but ceased in the Birmingham area because of the low grade of the ores and difficulty in beneficiating to compete with foreign ore. Scattered brown iron ore mines of the Clayton Formation in Georgia and Alabama extend this district about 500 miles eastward. These are small operations with limited production.

The mines in New York, New Jersey, and Pennsylvania in the Appalachian Range serve markets in these three States and make up the Northeastern States district.

The mines in the Western States have so little in common that it is difficult to discuss them as a group. The iron ore mining industry in Wyoming was established principally to serve the steel plants in Colorado and Utah. Mines in Utah also serve these plants. Mines in California produce for the local steel industry and for export ore to Japan. Mines in Nevada produce almost entirely for export to Japan. Mines in Texas supply steel mills at Dangerfield and Houston, and those in Missouri ship ore mainly to a nearby steel mill in southern Illinois and to mills in Indiana and Pennsylvania. U.S. mines operating in 1970 are given in table 30.

Marketing

Essentially all domestic iron ore is sold on the basis of a guaranteed analysis, which is achieved by beneficiation and/or blending and grading. The blending begins by selective sequential mining, so that as it leaves the mine the material will be consistent and uniform in grade and physical characteristics. Ore that is beneficiated and agglomerated near the mine site is in final form for marketing. Natural ore and some concentrates, however, may be further blended in the process of transporting and transferring ores from railroad trains to ore-carrying ships. In some instances a sequence fo unloading railroad cars onto storage piles is arranged to obtain uniform grade throughout the piles.

The technology of grading and blending the wide variety of iron ores to obtain a uniform product is well developed in the Lake Superior district. The ore body is sampled in place and ore cars or trucks are loaded in a sequence to obtain as much uniformity as is practical. Ore in the cars is sampled when cars leave the mine. When the cars arrive at railroad yards near loading docks the carloads are mixed in trains, so that each train has close to the desired uniformity of grade. Mixing occurs as the ore cars are dumped into loading pockets at the docks; when the ore is drawn from the pockets into the ships, it is further blended. The end result is a uniform material of known composition.

Transportation

Most domestic iron ore originating outside of of the Lake Superior district reaches consuming points in railroad cars. The railroad companies are developing multicar unit trains, especially for iron ore, which shuttle between the mine and the destination. Most Lake Superior ore is transported in Great Lakes iron ore carriers ranging up to 45,000-ton capacity. Those hauling ore that originates on the shores of Lake Superior pass through the Sault Sainte Marie locks, which limits their size to 1,200 by 110 ft. Since the Great Lakes transportation system is closed by ice three or four months out of the year, the mines stock ore for future shipment or cease operations during the winter months. Most of the direct shipping mines and those producing wash and gravity concentrate ores close down. However, mines with complex beneficiation plants operate year round.

Table 30.—Principal operating iron ore mines and beneficiating plants of the United States, 1970-71

Owner and operating company	Mine or mill	Location	Remarks
Bethlehem Mines Corporation	Cornwall	Cornwall, Pa.	--
	Grace	Morgantown, Pa.	--
Cites Serviice Co., Inc.: Chemical and Metals Group	Copperhill Operations	Copperhill, Tenn.	--
Cleveland-Cliffs Iron Company	Canisteo	Coleraine, Minn.	--
	Ore improvement plant	Eagle Mills, Mich.	--
Empire Iron Mining Co.	Empire	Palmer, Mich.	--
Humboldt Mining Co.	Humboldt	Humboldt, Mich.	Closed 1970.
Marquette Iron Mining Co.	Eagle Mills	Eagle Mills, Mich.	To close January 1971.
Do	Republic	Republic, Mich.	--
Mesaba-Cliffs Mining Co.	Hill-Trumbull	Marble, Minn.	--
Negaunee Mine Co., The	Mather	Negaunee, Mich.	--
Pioneer Pellet Plant	Pioneer plant	Eagle Mills, Mich.	--
Coons-Pacific Co.	Coons-Pacific concentrator	Eveleth, Minn.	--
Colorado Fuel & Iron Corp.	Sunrise	Guernsey, Wyo.	--
Do	Comstock	Cedar City, Utah	Operated by Utah Construction and Mining Corp.
Hanna Mining Company:			
Butler Pellet Project	Butler Taconite	Cooley, Minn.	--
Do	Groveland	Iron Mountain, Mich.	--
Do	Lauretta	Crosby, Minn.	Closed 1970.
Do	West Hill	Grand Rapids, Mich.	Closed 1970.
Do	Pierce Group	Hibbing, Minn.	--
National Steel Pellet Plant	National Steel Pellet Plant	Keewatin, Minn.	--
Pilot Knob Pellet Co.	Pilot Knob	Pilot Knob, Mo.	--
Inland Steel Company	Sherwood	Iron River, Mich.	--
Jackson County Iron Co.	Black River Falls	Black River Falls, Wis.	--
Jones & Laughlin Steel Corporation	Benson	Star Lake, N.Y.	--
Do	Lind-Greenway	Grand Rapids, Minn.	--
Do	Hill Annex	Calumet, Minn.	--
Do	McKinley	McKinley, Minn.	--
Do	Tracy	Negaunee, Mich.	To close January 1971.
Kaiser Steel Corporation	Eagle Mountain	Eagle Mt., Calif.	--
Lone Star Steel Company	Lone Star	Lone Star, Tex.	--
Meramec Mining Company	Pea Ridge	Sullivan, Mo.	--
NL Industries, Inc.	MacIntyre Development	Tahawus, N.Y.	--
Nevada-Barth Corporation	Barth	Carlin, Nevada	--
Oglebay Norton Company: Eveleth Taconite Co.	Thunderbird Mine	Eveleth and Virginia Cities, Missabe Mountain Twp., Minn.	--
	Fairlane Plant	Forbes, Minn.	--
Pickands Mather & Co.:			
Balkan Mining Co.	Danube	Bovey, Minn.	To close 1971.
Erie Mining Co.	Hoyt Lakes Plant	Hoyt Lakes, Minn.	--
Mahoning Ore & Steel Co.	Mahoning	Hibbing, Minn.	--
Pittsburgh Pacific Company	Dunwoody	Balkan Twp., Minn.	--
Do	Julia	Virginia, Minn.	--
Do	Gilbert	Gilbert, Minn.	--
Do	Louise	Irondale Twp., Minn.	--
Do	Monroe-Tener	Chisholm, Minn.	--
Do	Wyoming	Franklin, Minn.	--
Pitkin Iron Corp.	Pitkin	Cooper Basin, Colo.	--

Table 30.—Principal operating iron ore mines and beneficiating plants of the United States, 1970-71—Continued

Owner and operating company	Mine or mill	Location	Remarks
Republic Steel Corporation	Port Henry	Mineville, N.Y.	To close 1971.
Reserve Mining Company	E. W. Davis Works	Silver Bay, Minn.	--
Do	Peter Mitchell	Babbitt, Minn.	--
Rhude & Fryberger, Inc.	Gross-Nelson	Eveleth, Minn.	--
Do	Hull-Rust	Hibbing, Minn.	--
Shook & Fletcher Iron Co.	Blackburn	Russellville, Ala.	--
Snyder Mining Company	Whiteside	Buhl, Minn.	--
Standard Slag Company	Minnesota Claims	Wabuska, Nev.	To close 1971.
United States Pipe and Foundry Co.	Russellville	Russellville, Ala.	--
U.S. Steel Corp.:			
Minnesota Ore Operations	Diamond	Taconite, Minn.	--
Do	Arcturus	Marble, Minn.	--
Do	Minntac	Mt. Iron, Min.	--
Do	Plummer	Taconite, Minn.	--
Do	Rouchleau	Virginia, Minn.	--
Do	Sherman	Chisholm, Minn.	--
Do	Stephens	Aurora, Minn.	--
Do	Trout Lake plant	Coleraine, Minn.	--
Western Ore Operations:			
Atlantic City Ore Operations	Atlantic City	Lander, Wyoming	--
Utah Ore Operations	Desert Mound	Cedar City, Utah	--
Utah Mining & Construction Co.	Iron Springs	Iron Springs, Utah	--
Do	McCahill-Thompson	do	--
Woodward Iron Co.	Pyne	Bessemer, Ala.	Closed December 1970.

Stocks

Stocks of iron ore at mines accumulated during the winter reach more than 12 million tons by the end of January when they are measured for the annual inventory, and probably approach 20 million tons before the Great Lakes shipping season starts again in March or April. The iron ore inventory at year's end at consuming plants has reached 60 million tons in the last decade; about 55 million tons has been considered normal. Ship docks at lower ports in the past have stored as much as 10 million tons, but they are losing significance as a point of storage and have not held more than 4 million tons at any one time since 1964.

Prices

Iron ore prices range from about $5 per ton for some of the brown ores in the Southeastern district to $15 per ton for high-grade iron ore agglomerates in the Northeastern and Western districts. These are published prices and indicate the range in which a buyer can expect to obtain ore on the open markets. As a practical matter, how-

Table 31.—Stocks of iron ore at mines, December 31, 1942-70

(Thousand long tons)

Year	Stocks	Year	Stocks
1942	3,367	1956	5,465
1943	5,170	[1] 1957	6,776
1944	4,137	1958	7,033
1945	4,432	1959	7,358
1946	5,339	1960	12,337
1947	6,036	1961	10,335
1948	6,285	1962	[2] 11,614
1949	5,334	1963	[2] 10,738
1950	5,726	1964	[2] 10,241
1951	5,599	1965	[2] 12,667
1952	5,528	1966	[2] 12,160
1953	5,706	1967	12,959
1954	7,078	1968	16,041
1955	4,281	1969	13,790
----	----	1970	15,316

[1] Beginning in 1957 totals include all agglomerates plus manganiferous iron ores.
[2] Excludes byproduct ore.

Table 32.—Consumers stocks of iron ore and sinter, at consuming plants, December 31, 1942-70

(Thousand long tons)

Year	Stocks	Year	Stocks
1942	40,767	1956	47,292
1943	38,338	1957	53,175
1944	32,915	1958	53,599
1945	34,642	1959	53,038
1946	33,662	1960	61,569
1947	33,393	1961	58,869
1948	37,145	1962	59,553
1949	37,024	1963	54,971
1950	34,918	1964	54,189
1951	40,953	1965	53,799
1952	43,131	1966	54,658
1953	45,242	1967	55,121
1954	43,139	1968	53,232
1955	44,358	1969	51,003
----	-----	1970	52,781

Table 33.—Stocks of iron ore at U.S. docks, December 31, 1942-70

(Thousand long tons)

Year	Stock at dock	Year	Stock at dock
1942	6,821	1956	4,558
1943	6,209	1957	5,160
1944	4,941	1958	5,577
1945	4,399	1959	7,575
1946	4,409	1960	6,839
1947	4,436	[1] 1961	6,100
1948	4,903	1962	6,429
1949	6,085	1963	5,347
1950	5,398	1964	3,741
1951	6,396	1965	2,494
1952	6,116	1966	2,707
1953	7,671	1967	2,987
1954	6,591	1968	2,797
1955	4,918	1969	2,648
		1970	3,403

[1] Prior to 1961, for Lake Erie only.

Source: Lake Superior Iron Ore Association and American Iron Ore Association.

ever, most iron ore prices are negotiated between buyer and seller. The contracts involve time and delivery considerations besides price, and more than 80 percent of the ore is produced by captive mines (mines producing for company smelters) and therefore does not reach the open market. Prices for Lake Superior ores are governed by the Lake Erie price, which is established each year by the publication of a major contract between a prominent iron ore producer and a steel corporation. Historically it has been the first contract of the year, published before the start of the shipping season. Lately, however, the Lake Erie price has been steady, except for small changes in transportation costs. From 1962 until 1970, when increases were again made, most independent ore merchants served notice early in January of each year that prices would be unchanged.

The Lake Erie price is based on a standard ore containing 51.5 percent iron for a long ton, delivered at the rail of a vessel at the lower Lake ports. Prices are adjusted in proportion to the iron content above or below 51.5 percent iron with penalties for excess impurities and premiums for lump structure and high manganese content:

Price Adjustment for Phosphorus

Phosphorus content lower than 0.045 percent commands a premium, determined in accordance with the standard table of phosphorus values.

Penalties

In addition to the standard deductions for iron contents of less than 50 percent, which are computed as described in Chapter II under Grades and Definition, arbitrary penalties are also exacted for high silica and for fine structure.

Premiums for Lump Structure and High Manganese Content

Hard ores of high-iron, low-silica contents are often sold as lump grade, generally being priced as Old Range Non-Bessemer plus premiums for lump structure.

Ores containing in excess of 5 percent natural manganese are recognized as standard manganiferous iron ores and are generally priced as Old Range Non-Bessemer on the combined natural iron and manganese content, plus a premium for the natural manganese in excess of 5 percent. Ores containing between 2 and 5 percent of natural manganese are also sometimes marketed as manganiferous at prices which recognize some small value for the manganese content.

Premiums for lump structure and high manganese content vary and are determined by negotiation between buyer and seller.

Physical, Financial, and Corporate Structure of Selected Companies

Two-thirds of the domestic iron ore consuming plants are within a 250-mile radius of Toledo,

Ohio, on the southern shore of Lake Erie. The outlying points of consumption are (1) steel plants in eastern Pennsylvania; (2) the largest steel plant in the world at Sparrows Point, Md., just outside Baltimore; (3) steel plants in the Birmingham district of Alabama; and (4) individual plants in California, Colorado, Texas, and Utah. Blast furnaces in the United States are listed by geographic location in Table 34.

The domestic iron mining industry can be divided into three parts.

1. Companies that mine iron ore principally for their own use. These integrated steel and iron companies are the following:

Armco Steel Corp.
Bethlehem Steel Company
CF&I Steel Corp.
Inland Steel Co.
Jones & Laughlin Steel Corp.
Kaiser Steel Corp.
Lone Star Steel Co.
National Steel Corp.
Republic Steel Corp.
U.S. Pipe & Foundry Co.
United States Steel Corporation

2. Independent mining companies that produce ore under contract with others or for sale on the open market, as follows:

The Cleveland-Cliffs Iron Co.
The Hanna Mining Co.
Nevada-Barth Corp.
Oglebay Norton Co.
Picklands Mather & Co.
Pittsburgh Pacific Co.
Rhude & Fryberger, Inc.
Snyder Mining Co.
The Standard Slag Co.

Independent companies make up less than 20 percent of the industry, but in several instances an independent company has been retained to manage jointly financed large-scale operations.

3. Joint ventures of two or more companies that have been formed to mine on a scale larger than any one company could practically support, as follows:

The Marquette Iron Mining Co.
Manager and Operator: The Cleveland-Cliffs Iron Co.
Owners:
  The Cleveland-Cliffs Iron Co.
  International Harvester Co.
  Jones & Laughlin Steel Corp.
  The Wheeling-Pittsburgh Steel Corp.
Erie Mining Co.
Manager and Operator: Pickands Mather & Co.
Owners:
  Bethlehem Steel Corp.
  Interlake Steel Corp.
  The Steel Co. of Canada, Ltd.
  The Youngstown Sheet & Tube Co.
Pioneer Pellet Plant
Manager and Operator: The Cleveland-Cliffs Iron Co.
Owners:
  Bethlehem Steel Corp.
  The Cleveland-Cliffs Iron Co.
  McLouth Steel Corp.
  Republic Steel Corp.
Eveleth Taconite Co.
Owners:
  Ford Motor Co.
  Oglebay Norton Co.
Reserve Mining Co.
Owners:
  Armco Steel Corp.
  Republic Steel Corp.
Pilot Knob Pellet Co.
Owners:
  Granite City Steel Co.
  The Hanna Mining Co.
Butler Taconite Project
Operator: The Hanna Mining Co.
Owners:
  Inland Steel Co.
  The Hanna Mining Co.
  Wheeling-Pittsburgh Steel Corp.
Meramec Mining Co.
Owners:
  Bethlehem Steel Corp.
  St. Joe Minerals Corp.
Humboldt Mining Co.
Owners:
  The Cleveland-Cliffs Iron Co.
  Ford Motor Co.
Empire Iron Mining Co.
Manager and Operator: The Cleveland Cliffs Iron Co.
Owners:
  The Cleveland-Cliffs Iron Co.
  Inland Steel Co.
  International Harvester Co.
  McLouth Steel Corp.
The Negaunee Mine Co.
Manager and Operator: The Cleveland-Cliffs Iron Co.
Owners:
  Bethlehem Steel Corp.
  The Cleveland-Cliffs Iron Co.
  McLouth Steel Corp.
  Republic Steel Corp.
The Mesaba-Cliffs Mining Co.
Manager and Operator: The Cleveland-Cliffs Iron Co.
Owners:
  The Cleveland-Cliffs Iron Co.
  Detroit Delaware
  Jones & Laughlin Steel Corp.
  National Steel Corp.
  Wheeling-Pittsburgh Steel Corp.
National Steel Pellet Project
Manager and Operator: The Hanna Mining Co.
Owners:
  The Hanna Mining Co.
  National Steel Corp.

Steel companies in the United States are generally vertically integrated from the production

Table 34.—Location of U.S. iron blast furnaces, 1967

Plant location and operating company	Number of stacks
PITTSBURGH-YOUNGSTOWN DISTRICT	
Kentucky: Ashland: Armco Steel Corp.	8
Ohio (Youngstown area):	
Campbell: Youngstown Sheet & Tube Co.	4
Hubbard. Valley Mould and Iron Corp.	1
Warren: Republic Steel Corp.	1
Youngstown:	
Republic Steel Corp.	4
United States Steel Corp.	4
Youngstown Sheet & Tube Co.	2
Total	16
Ohio (central and south):	
Canton: Republic Steel Corp.	1
Jackson: Jackson Iron & Steel Co.	1
Massillon: Republic Steel Corp.	1
Middletown: Armco Steel Corp.	1
New Miami: Armco Steel Corp.	2
Portsmouth: Detroit Steel Corp.	2
Steubenville: Wheeling Steel Corp.	5
Total	13
Pennsylvania (western, excluding Pittsburgh area):	
Aliquippa: Jones & Laughlin Steel Corp.	5
Erie: Interlake Steel Corp.	1
Farrell: Sharon Steel Corp.	2
Johnstown: Bethlehem Steel Co.	6
Midland: Crucible Steel Co. of America	3
Monessen: Pittsburgh Steel Co.	3
Sharpsville: Shenango, Inc.	2
Total	22
PITTSBURGH-YOUNGSTOWN DISTRICT—	
Pennsylvania (Pittsburgh area):	
Braddock: United States Steel Corp.	6
Clairton: United States Steel Corp.	1
Duquesne: United States Steel Corp.	5
McKeesport: United States Steel Corp.	4
Neville Island: Shenango, Inc.	2
Pittsburgh: Jones & Laughlin Steel Corp.	6
Rankin: United States Steel Corp.	5
Total	29
West Virginia:	
Weirton: Weirton Steel, Division of National Steel	4
Total, Pittsburgh-Youngstown district	87

Table 34.—Location of U.S. iron blast furnaces, 1967—Continued

Plant location and operating company	Number of stacks
CHICAGO DISTRICT	
Illinois:	
Chicago:	
Interlake Steel Corp.	2
International Harvester Co.	3
Republic Steel Corp.	1
United States Steel Corp.	11
Youngstown Sheet & Tube Co.	3
Granite City: Granite City Steel Co.	2
Total	22
Indiana:	
East Chicago:	
Inland Steel Co.	8
Youngstown Sheet & Tube Co.	3
Gary: United States Steel Corp.	12
Total	23
Minnesota:	
Duluth: Unted States Steel Corp.	2
Total, Chicago district	47
CLEVELAND-DETROIT DISTRICT	
Michigan:	
Dearborn: Ford Motor Co.	8
River Rouge: Great Lakes Steel Corp. Div. of National Steel	4
Trenton: McLouth Steel Corp.	2
Total	9
Ohio (lake area):	
Cleveland:	
United States Steel Corp.	2
Jones & Laughlin Steel Corp.	3
Republic Steel Corp.	6
Lorain: United States Steel Corp.	5
Toledo: Interlake Steel Corp.	2
Total	18
Total, Cleveland-Detroit district	27
EASTERN DISTRICT	
Maryland:	
Sparrows Point: Bethlehem Steel Co.	10
New York:	
Buffalo:	
Hanna Furnace Corp.	4

Table 34.—Location of U.S. iron blast furnaces, 1967—Continued

Plant location and operating company	Number of stacks
Republic Steel Corp.	2
Lackawanna: Bethelehem Steel Co.	7
North Tonawanda: Tonawanda Iron Div.	1
Troy: Republic Steel Corp.	1
Total	15
Pennsylvania (eastern):	
Bethlehem: Bethlehem Steel Co.	5
Fairless Hills: United States Steel Corp.	3
Sheridan: Lavino & Co., E. J.	[1] 1
Swedeland: Alan Wood Steel Co.	2
Total	11
Total, Eastern district	36
WESTERN DISTRICT	
California: Fontana: Kaiser Steel Corp.	4
Colorado: Pueblo. C. F. & I. Steel Corp.	4
Utah:	
Geneva: United States Steel Corp.	3
Ironton: United States Steel Corp.	2
Total	5
Total, Western district	13
SOUTHERN DISTRICT	
Alabama:	
Birmingham:	
Republic Steel Corp.	2
United States Pipe & Foundry Co.	2
Ensley: United States Steel Corp.	5
Fairfield: United States Steel Corp.	3
Gadsden: Republic Steel Corp.	2
North Birmingham: United States Pipe & Foundry Co.	1
Woodward: Woodward Iron Co.	4
Total	19
Tennessee:	
Lyles-Wrigley:	
Merritt-Chapman & Scott Corp.: Tennessee Products & Chemical Corp.	1
Rockwood: Woodward Iron Co.	2
Total	3

Table 34.—Location of U.S. iron blast furnaces, 1967—Continued

Plant location and operating company	Number of stacks
SOUTHERN DISTRICT—Continued	
Texas: Houston: Sheffield Division of Armco Steel Corp.	1
Lone Star: Lone Star Steel Co.	1
Total	2
Virginia: Lynchburg: Lavino & Co.	[1] 2
Total, Southern district	26
Total all districts	236

[1] Ferromanganese only.
Source: American Iron and Steel Institute.

of raw materials to the production of semifinished steel and industrial shapes.

The larger steel companies produce their own coal, coke, limestone, and some manganese and ferroalloy metals ore, in addition to iron ore that they produce for their own use. In a few instances these companies produce iron ore for sale. The older and larger steel companies own or control some parts of the transportation systems that bring raw materials to the steel mills. A few own rail lines complete with rolling stock. Many own or have an interest in ocean-going ships, lake carriers, and barges, and many integrated steel companies are engaged in international operations.

The industrial trend toward diversification is beginning to affect the iron and steel industry. Kaiser Steel Corp. is a subsidiary of Kaiser Industries Corp. Control of the Lone Star Steel Co. was acquired recently by Philadelphia and Reading Corp., a holding company. Several mergers between iron and steel companies and nonferrous metal mining and fabricating companies as well as nonmetal companies have occurred; Jones & Laughlin Steel Corp. became part of Ling-Temco-Vought, Inc., Woodward Iron Co. was taken over by the Mead Corp., and Youngstown Sheet and Tube Co. became a wholly-owned subsidiary of Lykes-Youngstown Corp.

The following information on the physical, financial, and corporate structure of selected companies engaged in the iron ore industry was compiled from financial and trade publications and from individual company reports. The information applies to 1969. It is believed to be reasonably cor-

rect, but is known to be incomplete and more general than specific.

Steel Companies

Alan Wood Steel Co.—Capitalization: 2,000,000 shares authorized, 748,012 shares outstanding of common stock at $5 per; 45,074 shares authorized, 43,130 shares outstanding of preferred stock at $100 par.

Alan Wood is one of the smaller integrated steel companies in the United States. It is engaged in the manufacture and sale of steel and steel products including plain and diamond-patterned floor plates, grit-impregnated floor plates, hot- and cold-rolled strip and sheets, and semifinished products in the form of ingots, billets, and slabs. The company owns inactive iron mines in New Jersey; these were closed in 1966. In 1969 the company purchased iron ore, scrap, coal, limestone, and ferroalloys, but operated its own coke ovens and sold industrial and foundry coke and coal chemicals.

Bethlehem Steel Corp.—Capitalization: 80,000,000 shares authorized, 43,987,052 shares outstanding of common stock at $8 per share par value.

Bethlehem Steel Corp. is the second largest steel producer in the United States. It has 31 subsidiaries, 25 of which are wholly owned and consolidated. The six unconsolidated subsidiaries are 51 to 66.6 percent owned. It owns 45 percent of the Erie Mining Co., Youngstown Sheet and Tube Co., Interlake Iron Corp., and Stelco Coal Co. own the remainder. Bethlehem produces practically the entire gamut of steel products—sheet and strip, structural shapes, plates, bars, piling, tubular products, railroad products, industrial fasteners, forgings, castings, and fabricated steel structures such as bridges, buildings, pressure vessels, and corrugated culvert pipe. The corporation engages in shipbuilding and has its own ship repair shop. It mines iron ore, coal, and limestone chiefly for its own use, and it owns Meramec Mining Co. jointly with St. Joseph Lead Co. It is engaged in the transportation of ore, coal, limestone, and steel products on the Great Lakes and from foreign ports to the United States, and in the transportation of steel products between Atlantic, Gulf, and Pacific ports. It operates short line railroads in the vicinity of its iron and steel businesses. Bethlehem mines iron ore in Canada, Chile, and Venezuela and has an interest in iron deposits in Brazil, Liberia, and Gabon.

CF&I Steel Corp.—Capitalization: 10,000,000 shares authorized, 3,892,627 shares outstanding of common stock at $5 par.

CF&I Steel Corp. is one of the smaller integrated steel companies of the United States. Its principal business is the manufacture of iron and steel and the sale of diversified steel products including rails, rail fastenings, seamless tubing, casing, merchant steel, mining specialties, wire rope and strand, rod, wire, and wire products, and cold-rolled products. It sells coke and coke byproducts. It mines its own iron ore, coal, and limestone and owns and operates a railroad with 113 miles of track, 692 cars, and 23 diesel locomotives.

Jones & Laughlin Steel Corp.—Capitalization: 20,000,000 shares authorized, 15,878,126 shares outstanding of common stock at $10 par; 293,568 shares authorized, 207,206 shares outstanding of preferred stock (5 percent cumulative) at $100 par.

Jones & Laughlin Steel Corp. is one of the medium-size integrated steel companies of the United States. Its principal business is the production and sale of carbon alloy and stainless steel, billets, slabs, skelp, bars, small shapes, rods, wire, structural shapes, railroad spikes, junior beams, channels, hot-rolled sheets and strip, electrical sheets, a whole range of light consumer goods, and galvanized consumer products. It produces coke primarily for its own use and sells byproducts made in the manufacture of coke. Jones & Laughlin mines its own iron ore, coal, and limestone. It owns and operates a fleet of diesel river tow boats and barges. Additionally, it owns and operates the following common carriers: Monongahela Connecting Railroad Co., Aliquippa & Southern Railroad Co., and Cuyahoga Valley Railway Co. The corporation operates its own iron ore mines in the Lake Superior district, owns and operates the Adams mine in Canada, and owns a minority interest in subsidiary mining companies in the United States. It also owns a 50-percent interest in the Bristol Quebec Mining Co., which, in turn, owns a 50-percent interest in Hilton Mines, Inc., a Quebec, Canada, mining and pelletizing operation. Since Mar. 13, 1969, the company has been controlled by Ling-Temco-Vought, Inc.

Kaiser Steel Corp.—Capitalization: 15,000,000 shares authorized, 6,692,777 shares outstanding of common stock at $0.66⅔; 1,084,957 shares authorized, 1,084,957 shares outstanding of preferred stock (1.46 percent cumulative).

The Kaiser Steel Corp. is effectively controlled by Kaiser Industries Corp., which at the end of 1966 owned 78 percent of the common shares. Kaiser Steel is a medium-size, fully integrated steel company, the only one that operates an in-

tegrated steel plant on the Pacific coast. There it produces plate, tubular products, carbon and alloy bars, hot- and cold-rolled strip, hot- and cold-rolled sheets, galvanized steel, sheets, structural shapes, and tin plates, and produces pig iron and ingot molds for sale. The company mines iron ore, coking coal, and limestone for its own use and produces iron ore concentrates and pellets for sale to Japan.

Republic Steel Corp.—Capitalization: 50,000,000 shares authorized, 15,846,521 shares outstanding at $10 par; 10,000,000 shares authorized, 0 shares outstanding of preferred stock at $100 par.

Republic Steel Corp. is the third largest steel producer in the United States. In addition to essentially the entire range of steel products, it produces and sells a wide variety of light consumer-good steels that are used in automobiles, household appliances, and commercial building equipment. It is one of the principal producers of alloy and stainless steels. It owns and operates iron ore, coal, and limestone mines under lease, and owns Great Lakes ore carriers. Republic owns a 5-percent interest in the Iron Ore Co. of Canada, through a wholly owned subsidiary. It has a major interest in the Liberian Mining Co., and it owns half of Reserve Mining Co.

Philadelphia & Reading Corp.—Capitalization: 263,652 shares authorized, 248,532 shares outstanding of preferred stock at $100 par.

Philadelphia & Reading Corp., a subsidiary of Northwest Industries, Inc., is a holding company that stemmed from the Philadelphia & Reading Coal & Iron Co. It acquired voting control of the Lone Star Steel Co. in 1965 and all Lone Star stock through an exchange on Apr. 1, 1966. Lone Star is a fully integrated steel company producing principally steel products for the oil and gas industry of the Southwest. It operates its own iron, coal, and limestone mines, producing only for its own use.

United States Steel Corp.—Capitalization: 90,000,000 shares authorized, 54,145,212 shares outstanding of common stock at $30 par; 20,000,000 shares authorized of preferred stock.

The United States Steel Corp. is the largest steel company in the world (1970) and is a major producer of coal, coal chemicals, and cement. It produces and sells carbon steel ingots, blooms, billets, slabs, tubes, rounds, skelp, structural shapes, pilings, plates, rails, rail accessories, hot and cold rolled sheets, strip, plate, tin plate and tubing, rods, wire and wire products, forgings, armor plate, carbon steels, and many of the above items in stainless steel. The corporation fabricates and erects steel structures such as bridges, buildings, large diameter steel pipes, oilfield equipment, and other products made of steel. It carries steel manufacturing further than most other steel companies in that one division manufactures and sells prefabricated steel houses.

The corporation operates iron ore, limestone, and coal mines and manufactures coke chemicals. It also owns and operates several common carrier railroads and a Great Lakes shipping fleet. United States Steel Corp. owns the Orinoco Mining Co. in Venezuela and the Quebec Cartier Mining Co. in Quebec, Canada.

Joint Venture Companies

Armco Steel Corp.—Capitalization: 60,000,000 shares authorized, 29,196,630 shares outstanding of common stock at $5 par.

Armco is one of the six largest integrated steel companies in the United States. It produces carbon alloy and stainless steel billets, slabs, skelp, bars, strip, plate, and sheet. It fabricates oilfield equipment and corrugated metal culvert pipes, but it specializes in producing special steels for fabrication into consumer products by others. It owns and operates coal mines, but it has not operated its own iron mines since it suspended mining operations in Texas in 1963. Armco has an interest in iron ore transportation companies and in the Carroll Lake pellet plant, which is operated by the Iron Ore Co. of Canada.

Erie Mining Co.—Erie Mining Co. is jointly owned by Bethlehem Steel Corp., Youngstown Sheet and Tube Co., and Interlake Steel Corp. The Erie Mining Co. mine and plant in Minnesota has capacity to produce 10,300,000 tons of pellets per year. The operation is managed by the Pickands Mather & Co.

Eveleth Taconite Co.—Eveleth Taconite Co. is owned by the Ford Motor Co. and Oglebay Norton Co. Oglebay Norton manages the operation. The Eveleth Co. operates a mine and plant with capacity to produce 1,600,000 tons of pellets annually at Eveleth, Minn. The Ford Motor Co. is one of the three principal automobile manufacturers in the United States.

Interlake Steel Corp.—Capitalization: 10,000,000 shares authorized, 4,489,097 shares outstanding of common stock at $1 par.

The Interlake Steel Corp. is an integrated steel producer engaged principally in the sale and manufacture of pig iron, ferroalloys, coke and coal chemicals, steel ingots and slabs, plate, sheet, strip, and specialty items such as metal furniture, storage racks, and related products. Interlake Steel

Corp. owns interests in the following mining companies: Interlake Industries, Inc. (Delaware), Cornell, Palmer, and Mauthe Mining Companies (Michigan), Western Mining Co. and Ontario Mining Co. (Minnesota), Odonna Iron Co., Tilden Iron Mining Co., and Zenith Furnace Corp. (Wisconsin), and the Wabush iron ore project and the Wabush Pellet Co. (Canada).

Meramec Mining Co.—Meramec Mining Co. is owned by the St. Joseph Lead Co. and Bethlehem Steel Corp. It operates the Pea Ridge Iron Mine at Sullivan, Mo., which has an annual capacity of 2,000,000 tons of iron ore pellets.

Reserve Mining Co.—Reserve Mining Co. is owned jointly by Republic Steel Corp. and Armco Steel Corp. It has the capacity to produce 10.7 million tons of pellets per year. The financial structure of Republic Steel Corp. is described in the previous section.

St. Joseph Lead Co.—Capitalization: 10,000,000 shares authorized, 8,533,800 shares outstanding of common stock at $10 par.

The St. Joseph Co. mines, mills, and smelts lead and zinc ores in the United States, and through its subsidiaries owns and operates lead and zinc properties in Argentina and Peru.

Youngstown Sheet & Tube Co.—Capitalization: 25,000,000 shares authorized, 10,708,324 shares outstanding of common stock.

Youngstown Sheet and Tube Co., part of the Lykes-Youngstown Corp., is one of the larger integrated steel producers in the United States. As the name implies, its principal business is the manufacture of finished steel, pipe, sheets, bars, and tin plate. It is associated with the Erie Mining Co., the Palmer and Volunteer Mining Companies (Michigan), the Iron Ore Co. of Canada, Ontario Iron Co., Wabush Iron Co., Wabush Pellet Co., the Carroll Pellet Co. (Canada), Mahoning Ore and Steel Co. (Minnesota), and the Mauthe Mining Co. (Michigan). The company is also associated with the Mathes Coal Co. (Pennsylvania), the Carbon Limestone Co. (Ohio), the Presque Isles Corp. (Michigan), Carryore Ltd. (Canada), Iron Ore Transportation Co. Ltd. (Canada), Iron Ore Transportation Co. Ltd. (Canada) and Ore Transport, Inc. (Delaware),

Mining Companies

Iron mining companies range from very large independent ore merchants that produce millions of tons of iron ore per year from their own mines and from mines that they manage for other owners, to small mining companies owned by one or two men who mine iron ore when the market is up and they see an opportunity for profit. The smallest of these operate with only $50,000 to $100,000 in capital equipment and depend on the construction industry for most of their income.

The Cleveland-Cliffs Iron Co.—Capitalization: 7,000,000 shares authorized, 4,090,931 shares outstanding of common stock at $1 par; 500,000 shares authorized, 215,897 shares outstanding of preferred (4½ percent cumulative).

Cleveland-Cliffs is principally an operating mining company, but it also acts as a holding company and its subsidiaries are engaged in Great Lakes transportation, in timber and other forest products, and in real estate. The company has substantial holdings in securities of steel and other companies. The wide range of its operations can be judged by the following list of subsidiaries:

The Cleveland-Cliffs Steamship Co. (Del.) Lake transportation
Cliffs International, Inc. (Ohio)
Superior Realty Co. (Mich.), Real estate
Ishpeming Mining Co. Ltd. (Mich.)
Cliffs of Canada Ltd. (Canada)
Tetapaga Mining Co. Ltd. (Ohio)
Cliffs Western Australian Mining Co. Pty., Ltd. (Australia)
Lake Superior & Ishpeming R.R. Co., (Mich.)
Canisteo Mining Co. (Minn.)
Cliffs Realty Co. (Mich.)
Albanel Minerals Ltd. (Canada)
Marquette Iron Mining Co.
Arctic Iron Co. (Mich.)
Fox Cliffs Lumber Co.
Humboldt Mining Co. (Mich.)
Upper Peninsula Generating Co. (Mich.)

The Hanna Mining Co.—Capitalization: 9,000,000 shares authorized, 8,796,350 shares outstanding of common stock $1 par.

The Hanna Mining Co. produces iron ore and produces and processes nickel ore. It owns two Great Lakes cargo vessels and supervises the operation of 14 others. Its operations are worldwide. It owns shares in and is affiliated with the Iron Ore Co. of Canada; Hollinger North Shore Exploration Co., Ltd., of Canada; Labrador Mining and Exploration Co. Ltd. of Canada; Carroll Pellet Co., of Canada; St. John Del Ray Mining Co., Ltd., of Brazil; and through Geraldton Joint Venture, a subsidiary, it is engaged in iron ore mining in Australia.

Oglebay Norton Co.—Capitalization: 3,000,000 shares authorized, 1,006,251 shares outstanding of common stock at $1 par; 400,000 shares authorized, 148,950 shares outstanding of preferred stock (5½ percent).

The Oglebay Norton Co. is engaged principally in Great Lakes shipping and warehousing. Its coal and iron ore mining operations have become sec-

ondary in the last decade. The company owns and operates 18 ships on the Great Lakes and operates 10 coal mines in Ohio and West Virginia. It manages the Eveleth Taconite Co. at Eveleth, Minn., which has the capacity to produce 1,600,000 tons of pellets annually, and is the sales agent for Silver Bay pellets (Reserve Mining Co.) and Samitri iron ores (Minas Gerais, Brazil).

Pickands Mather & Co.—Pickands Mather & Co. was acquired in 1969 by Diamond Shamrock Corp. by an exchange of stock. Pickands Mather is an operating company engaged in the development and operation of iron ore and coal properties, principally for the account of major steel companies in the United States, Canada, and Japan.

Pickands Mather operates the Erie Mining Co., described above, it has 5-percent ownership in Wabash Mines Project, and it developed and managed construction of the Wabash plant. It is engaged, through a wholly owned subsidiary, in development of the Savage River Mines, an iron ore project in Tazmania, Australia, which is a joint venture between Cerro Corp., Pokantico International Corp., Chemical International Finance Ltd. and companies subsidiary, in association with a Japanese group consisting of Mitsubishi Shoji Kaisha, Lt., and Sumitomo Shoji Kaisha, Ltd. (trading companies), together with five Japanese steel companies. It acts as managing agent for the Hilton Mines (Quebec, Canada), Mahoning Ore and Steel Co. (Minnesota), Balkan Mining Co. (Minnesota), Western Mining Co. (Minnesota), and it acts as managing agent for Pikeville Coal Co., a subsidiary of the Steel Co. of Canada Ltd. The company owns and operates a fleet of 19 vessels on the Great Lakes and St. Lawrence Seaway, and its wholly owned subsidiary, the Labrador Steamship Co. Ltd., owns one vessel and operates another under charter with option to purchase. The company also has an ownership interest in, or manages operations of, docking facilities devoted to the transshipment of iron ore and coal between lake vessels and railroad cars. Through wholly or partly owned subsidiaries, it is employed on a year to year basis as stevedore at the docks of various railroad companies.

Principal Government and Industry Groups Concerned With the Iron Ore Industry

Government Agencies

Department of Commerce:
- Bureau of Census
  Washington, D.C. 20232.
- Business and Defense Services Administration
  Washington, D.C. 20230.
- Bureau of Standards
  Washington, D.C. 20234.
- Maritime Administration
  Washington, D.C. 20230.

Department of Defense,
- Department of the Army
  - Corp of Engineers–Rivers and Harbors
    Washington, D.C. 20500.

Department of the Interior:
- Bureau of Mines
  Washington, D.C. 20240
- Geological Survey
  Washington, D.C. 20240.
- Office of Mineral and Solid Fuels
  Washington, D.C. 20240.
- Office of Minerals Exploration
  Washington, D.C. 20240.

Department of Labor:
- Bureau of Labor Statistics
  Washington, D.C. 20210.

Department of State:
- Agency for International Development
  Washington, D.C. 20532.
- Bureau of Economic Affairs
  Industrial and Strategic Materials Division
  Washington, D.C. 20520.

Department of the Treasury:
- Bureau of Customs
  Washington, D.C. 20220.

Executive Offices of the President:
- Bureau of Budget
  Washington, D.C. 20500.
- Council of Economic Advisors
  Washington, D.C. 20500.
- Office of Emergency Preparedness
  Washington, D.C. 20500.

General Services Administration:
- Defense Materials Service
  Washington, D.C. 20405.

Tariff Commission:
- Washington, D.C. 20436.

Associations

American Institute of Mining, Metallurgical, and Petroleum Engineers
- 345 East 47th St.
  New York, N.Y. 10017.

American Institute of Steel Construction
- 101 Park Ave.
  New York, N.Y. 10017.

American Iron and Steel Institute
150 East 42nd St.
New York, N.Y. 10017.

American Iron Ore Association
600 Bulkley Building
Cleveland, Ohio 44115.

American Mining Congress
1100 Ring Building
1200 18th St., N.W.
Washington, D.C. 20036.

American Society for Metals
Metals Park, Ohio 44073.

Association of Iron and Steel Engineers
1010 Empire Building
Pittsburgh, Pa. 15222.

Blast Furnace Research, Inc.
2900 Grant Bldg.
Pittsburgh, Pa. 15219.

Concrete Reinforcing Steel Institute
38 South Dearborn St.
Chicago, Ill. 60603.

Ductile Iron Society
P.O. Box 858
Cleveland, Ohio 44122.

Eastern States Blast Furnace and Coke Oven Association
c/o W. F. Huntley

Jones & Laughlin Steel Corporation
Three Gateway Center
Pittsburgh, Pa. 15230.

Institute of Scrap Iron and Steel
1729 H St., N.W.
Washington, D.C. 20006.

Mineralogical Society of America
U.S. National Museum
Washington, D.C. 20560.

Mining and Metallurgical Society of America
11 Broadway
New York, N.Y. 10012.

National Academy of Sciences—National Research Council
2101 Constitution Ave., N.W.
Washington, D.C. 20418.

National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550.

Northwest Mining Association
522 West First
Spokane, Wash. 99201

Resources for the Future
1775 Massachusetts Ave., N.W.
Washington, D.C. 20036.

Steel Founders' Society of America
Westview Towers
21010 Center Ridge Road
Rocky River, Ohio 44116.

Steel Service Center Institute
540 Terminal Tower
Cleveland, Ohio 44135.

Labor Organizations

The United Steel Workers of America is the principal Union affiliation at domestic iron ore mines and mills (see table 21). However, unions of operating engineers, the building trades, and railroad workers have members working at many of the iron mines. These unions are affiliated with the AFL-CIO and their members follow the lead of the principal affiliate in their relations with the operating companies.

WORLD IRON MINING INDUSTRY

The iron mining industry of the world has grown spectacularly in the last quarter century. It produced about 300,000,000 tons of ore per year in the early 1950's and 754,500,000 tons in 1970. Its capacity to produce ore of the traditional grade and structure outran the world's needs about 1960. Since then, there has been a surplus of these ores even in years of abnormally high steel output.

The iron mining industry is widely scattered throughout the whole world, but there are notable concentrations in the Lake Superior districts and the Labrador trough of North America; the Minas Gerais area of Brazil in the Minette ore belt and the Scandinavian peninsula of Western Europe; in the magnetite ore deposits of the Urals and in the Ukraine of the Soviet Union, in the iron-bearing mountains of Western Africa, in the hematite deposits of India, and in the newly developing orefields of Western Australia.

The pattern of the world's iron mining industry is in many ways similar to that of the United States. A large part of it is controlled or influenced by steel producers who operate iron mines to assure a reliable, reasonably valued raw material supply. Iron ore mines in Communist countries are owned by the State, but in policy matters there is a tendency to lump the iron ore mines under heavy industry, the priorities for which invariably are dominated by the sector responsible for producing iron and steel. On the other hand, State-owned mines in Socialist countries such as Sweden and India resemble the independent segment of the U.S. industry. Most of these mines

conduct their operations in about the same manner as does private industry in a capitalistic society.

Probably the most significant variation from the iron-mining patterns of the United States are those of the developing countries where the mines are owned jointly by Government and private industry. But, as in the United States, in some parts of the world there are privately owned, autonomous operations that produce for the open market. The mines in Peru and some in India are notable examples.

The following information on the physical, financial, and corporate structures of selected companies engaged in the iron ore industry in foreign countries parallels that given for companies operating in the United States. It was compiled from financial and trade publications and from individual company reports and is known to be incomplete.

North America

Canada

Hollinger Consolidated Gold Mines, Ltd.—Capitalization: 5,000,000 shares authorized, 4,920,000 shares outstanding of common stock at Can$5 par.

Hollinger is engaged in mining iron ore and in mining and milling gold ore, and is actively interested in exploring, developing, mining, managing, and financing other mineral properties and mining companies. Its wholly owned and partially owned subsidiaries are as follows:

Labrador Mining & Exploration Co., Ltd.
Quebec, North Shore & Labrador Ry.
Ungava Power Co., Ltd.
Hollinger Ungava Transport, Ltd.
Kayorum Gold Mines, Ltd.
Holcorp Mines, Ltd.
Holannah Mines, Ltd.
Mountjoy Timber Co., Ltd.
Hollinger & Hanna, Ltd.

Hollinger and a group of American iron mining and steel companies, which included Armco Steel Corp., National Steel Corp., Wheeling Steel Corp., Republic Steel Corp., Youngstown Sheet and Tube Co., and Hanna Mining Co. formed the Iron Ore Co. of Canada to develop iron deposits in the Labrador trough, 300 miles north of Seven Islands, Quebec. The company built 360 miles of railroad, river-port storage and loading facilities, powerplants, and completely new communities to service the docks and mines.

Hollinger and subsidiaries with the Iron Ore Co. of Canada formed the Carol Pellet Co. which constructed an iron ore pelletizing plant with annual capacity of 5,500,000 tons of pellets at Carol Lake, Labrador.

Steep Rock Iron Mines Ltd.—Capitalization: 10,666,666 shares authorized, 8,063,652 shares outstanding of common stock at Can$1 par.

Steep Rock Iron Mines Ltd. owns iron ore mineral lands in Ontario, Canada, which are believed to be an extension of the Mesabi Range in the United States. The company mines part of the property for its own account and has leased 1,200 acres for 99 years to the Caland Ore Company Ltd., a subsidiary of Inland Steel Co.

Steel Co. of Canada, Ltd.—Capitalization: 35,000,000 shares authorized, 24,330,347 shares outstanding of common stock.

The Steel Co. of Canada, Ltd., is Canada's largest producer of pig iron, semifinished steel, barmill products, sheet, strip, plate, track fastenings, drop forgings, and other steel products. The company owns interests in the following coal and iron ore properties: In the United States: Mather Colleries, Corsica Iron Co., Banner Mining Co., Utica Mining Co., Balkan Mining Co., Lake Mining Co., Western Mining Co., Olga Coal Co., Ontario Coal Property, Ontario Iron Co., Erie Mining Co., Mathies Coal Co., Mauthe Mining Co.; and in Canada: Hilton Mines, Quebec; Clay and Howells Townships Property, Ontario; Wabush Mines, Newfoundland; and Labrador Corp., Ltd., Labrador.

Mexico

The iron ore industry of Mexico is essentially owned and controlled by the steel companies. Steel companies are, in turn, partially owned and influenced by Government agencies. Operation of the companies parallels that of privately owned concerns in the United States, but their products are geared to the needs of Mexico.

Altos Hornos de México, S.A.—Capitalization: 6,000,000 shares social capital at Mex$100 per share. Total accumulated investment in 1966 was Mex$2,800,000,000.

Altos Hornos is the largest integrated steel producer in Mexico. The company mines its own coal, iron ore, and manganese, and produces pig iron, and steel ingots, plate, sheet, nuts, bolts, nails, spikes, springs, ship's anchors, rods, wire, steel mesh, and staples. It also produces finished steel for the commercial market.

Cía Fundidora de Fierro y Acero de Monterrey, S.A.—Capitalization: Mex$525,000,000 social capital, which does not include Mex$50,000,000 au-

thorized in common stocks at Mex$100 per share, reserved for convertible obligations.

Fundidora is the second largest integrated steel producer in Mexico. Through its subsidiaries, Fundidora owns and operates coal, limestone, and iron ore mines. It produces pig iron, billets, structural shapes, rail, strip, plate, rods, and wire. Following is a list of its subsidiaries:

Cerro de Mercado, S.A., iron ore mining
Hullera Mexicana, S.A., Y Carbon y Cok, S.A., coal mining
Minera del Norte, S.A., manganese mining
Harbison Walker-Flir, S.A., refractories
Harbison Walker-Flir de Mexico, S.A., refractories
Compania Minera Norex, S.A., refractory materials
Cía Metalurgica México, S.A., finished steel products
Ferroaleaciones de México, S.A., ferroalloys
Estructuras de Acero, S.A., finished steel products
Tuberia Nacional, S.A., pipe and tube

Grupo Acero Hylsa.—Hylsa has integrated steel plants at Monterrey (Hojalata y Lámina S.A.), at Puebla (Hylsa de México, S.A.), and east of Mexico City. Most raw material for steelmaking is sponge iron from Fierro Esponja, S.A., another part of Hysla. The Grupo produces steel sheet, plate, strip, tube, pipe, reinforcing bars, and galvanized steel products. It produces its own iron ore through Las Encinas Compañía Minera at mines near Pihuamo, Jalisco. In 1966 the Grupo produced 475,000 tons of steel products and had a total investment of Mex$1,865,000,000. Principal companies in the group are as follows:

Fierro Esponja, S.A.
Hojalata y Lámina, S.A.
Aceros Alfa Monterrey, S.A.
Aceros de México, S.A.
Hylsa de México
Talleres Universales, S.A.

South America

The iron ore industry of South America is divided about evenly among mines that produce for export and mines that are owned and controlled by integrated steel companies.

Brazil

The iron ore industry of Brazil is dominated by the government-owned companies, Cía Vale do Rio Doce and Cía Siderúrgica Nacional (CSN). Cía Vale do Rio Doce is principally an iron mining concern. It produces iron ore for export and owns and operates railroads and ship loading docks. CSN owns and operates the Volta Rendonda steel plant, the largest integrated plant in Brazil. The plant produces pig iron; steel ingots, rail, structural shapes, plates, sheets, strip, rod, bars, galvanized sheet, and electrolytic tin plate; and ferroalloys. It operates its own iron ore mine and buys some ore from independent producers.

Cia Siderúrgica Belgo-Mineira.—Capitalization: Cr$147,000,000 capital.

Belgo Mineira is the largest integrated company in the private sector of Brazil. Ownership is divided between Belgian steel companies and Brazilian capital. The company operates its own iron mines, and grows and harvests timber on its own lands. The timber produced is used to make charcoal for company blast furnaces. It produces pig iron, steel ingots, reinforcing bars, rods, sheet, special structural sections, wire, and galvanized steel tubes and wire.

Minerações Brasileiras Reunidas, S.A. (MBR).—MBR is an operating company owned 49 percent by St. John del Rey Mining Co. and 51 percent by the Brazilian Antunes Group, Compañhia Auxiliar de Empresas de Mineração. Over 75 percent of the stock of St. John del Rey Mining Co. is owned by Hanna Mines, Ltd. (Hanna Mining Co., U.S.) The MBR is in the process of building an iron ore mining complex and shiploading facilities, which when completed will have capital expenditures totaling US$200,000,000. The mine and plant will have annual capacity to produce 1 million tons of direct-shipping iron ore and 2 million tons of iron ore pellets.

St. John del Rey Mining Co.—Capitalization: 2,000,000 shares authorized, 1,553,764 shares outstanding of common stock at £1 par; 100,000 shares authorized, 100,000 shares outstanding of preferred stock (10 percent) at £1 par.

Chile

Since the following information on iron mines in Chile was compiled the Chilean Government has nationalized all Gran Minera properties, and Cía Minera Santa Bábara, a Chilean firm, reportedly has taken over Cía Minera Santa Fe. Cía Minera Santa Fe is the largest iron ore producer in Chile. It operates iron ore mines on its own account and purchases ore from small operators. It is a stock company, 50 percent of which is owned by A. L. Engelhardt, a subsidiary of Howmet Corp., which acquired ownership by absorbing Minerals and Chemicals Philipp Corp. The other half is owned by investment companies principally in Canada and Chile.

Bethlehem-Chile Iron Mines Co.—The Bethlehem-Chile Co. is a subsidiary operating company of the Bethlehem Steel Co. of the United States. It produces iron ore for shipment to the parent

company and supplies ore to the Cía de Acero del Pacifico described below.

Cía de Acero del Pacifico (CAP).—CAP is the only integrated steel producer in Chile. It owns and operates the Algarroba iron ore mine, but sells the ore on the export market, principally to Japanese steel companies. Ore for its own operation is obtained at less than market value by agreement with Bethlehem-Chile Iron Mines Co. CAP was formed under government sponsorship to produce steel products for sale principally in Chile, but also to supply part of the needs of other South American countries. CAP produces pig iron, steel ingots, plate, sheet, strip, bars, rods, structural shapes, tubes, and tin plate.

Peru

The iron mining industry of Peru produces almost entirely for export. However, the Marcona Mining Co. supplies the government-owned steel plant at Chimbote with ore under an agreement that is part of its mining concession.

Cyprus Mines Corp.—Capitalization: 28,000,000 shares authorized, 9,791,000 shares outstanding of common stock at US$4 par.

Cyprus Mines Corp. (U.S.) engages in a wide variety of mining and lumber producing enterprises. It mines and concentrates copper and pyrite in the Republic of Cyprus and operates copper and zinc mines in Arizona.

Marcona Mining Co.—Marcona Mining Co. is jointly owned by Cyprus Mines Corp. and Utah Construction and Mining Company. Utah Construction is the operating company.

Utah Construction and Mining Co.—Capitalization: 20,000,000 shares authorized, 4,301,970 shares outstanding of common stock at US$2 par.

Utah Construction is a diversified general contracting, engineering, and mining company. It is affiliated through stock ownership with the Marcona Corp. and its subsidiaries, Cía San Juan, S.A. (Panama), Marcona Mining Co., Pima Mining Co., Goldsworthy Mining Co., Ltd. (Australia), and various other mining and construction companies.

Cía San Juan S.A. is Marcona's sales subsidiary and operates a bulk-carrier fleet to deliver iron ore to the markets of the world.

Venezuela

Iron ore is mined in Venezuela by the Orinoco Mining Co., a wholly owned subsidiary of the United States Steel Corp., and by the Iron Mines Co. of Venezuela, a wholly owned subsidiary of Bethelehem Steel Corp. By agreement, Orinoco Mining Co. supplies ore to the Government-owned Matanzas steel plant. Both companies operate rail lines and shiploading docks.

Europe

The European Coal and Steel Community (ECSC), is the most important single element in the structure of the iron ore mining industry of Europe. Community objectives are to establish conditions which will in themselves assure the most rational distribution of production at the highest possible level of productivity, while safeguarding continuity of employment and avoiding disturbances in the economies of the member States (West Germany, France, Belgium, Luxembourg, Italy, and the Netherlands). Coal, steel, and the raw materials for steel production, iron ore, coke, and scrap are treated as common resources so that member countries have equal access on equal terms. Tariffs, quotas, and public subsidies are eliminated among the members. Capital and labor circulate freely from one member nation to another. All iron mining in the member countries is influenced by the ECSC principles. However, individual companies within member States exercise essentially the same freedom of action as do comparable concerns outside the community.

The iron mining industry within the community is dominated by the steel producers who mine ore for their own use and for sale to others. Although in some instances iron mining companies are incorporated separately, they are captives of the steel plants. The poor market for the low-grade ore produced within the community has practically eliminated the independent iron ore mines.

Data on selected companies in Europe were obtained from annual financial reports, and trade publications. They are believed to be correct but are known to be incomplete.

France

The iron mining industry of the Lorraine basin which produces most of the iron ore in France is captive of the French steel industry. There is marked crossing of capital interests in the steel companies. Two groups of companies control more than three-fourths of the steel production in France. The groups are interrelated and linked to steel producers in Luxembourg, Germany, and Belgium. Coal mines in France have been nationalized, but the steel companies own coal mines in Belgium, the Netherlands, and West Germany. The Lorraine steel industry is vertically integrated,

producing coal, iron ore, and limestone, but it produces relatively little finished steel.

Usinor-Union Sidérurgique du Nord et de l'Est de la France.—Usinor mines calcareous and siliceous iron ores and limestone for its own account and for others. However, its principal steel plant at Dunkirk depends on imported ore. It is a fully integrated steel company and produces iron and steel castings and forgings, semifinished steel for rerolling and for seamless tubes, standard railroad material, structural shapes, sheet piling, merchant bars, squares, flats, concrete reinforcing rods, rounds, hot-rolled strip, plates, sheets, and plain and corrugated galvanized sheets. Its tube division produces welded and seamless gas pipes, seamless boiler tubes for all purposes, drill pipe casing, pipe for pipelines and refineries, flanged pipes for mines, large-diameter welded and seamless pipes for underground conduits and similar tubular material.

Wendel-Sidélor.—Capitalization: Fr560,000,000.

Wendel-Sidélor was formed in 1968 by merger of Union Sidérurgique Lorraine S.A. (Sidelor), Société Mosellane de Sidérurgie (SMS), and de Wendel & Cie. The company operates its own iron ore and coal mines, coke plants, and iron foundry, and produces pig iron and steel blooms, billets, slabs, structural shapes, rails, sheets, bars, heavy, medium, and light sections, wire, rods, rails, sheet piling, hot-dipped tin plate, castings, seamless tubes, wire, wire products, and welded wire mesh.

Federal Republic of Germany

The iron ore mining industry of West Germany has been almost entirely directed by the steel companies since the last of the independent iron ore producers was forced out of business by competition from high-grade imported ores about 1965. In the last decade the steel companies of West Germany have been concentrating into groups through purchase of each other's stocks or by outright mergers and amalgamations. They have been encouraged by the ECSC to do so in the interest of the efficiency that results from large-scale operations. Essentially all the steel industry and hence the iron ore industry of West Germany is controlled by the following groups: Thyssen, Mannesmann - Hoesch, Krupp, Dortmund - Horder, Klockner, Haniel, and Rheinische. The German steel companies participate in financing some foreign iron ore mining operations. The only significant exception to the above and to private industry is the Government-owned Huttenwerke Salzgitter and partially owned Huttenwerke Ilseder.

August Thyssen-Hutte A.G.—Capitalization: DM1,016,000 authorized DM906,000,000 outstanding in common stock, DM100, DM1,000, DM3,000 par.

The Thyssen group is the largest of the steel producers in West Germany. It is a completely integrated company and produces its own iron ore, coal, and limestone. It operates a coking plant and ore preperation and sintering plant and produces pig iron, crude steel, rough-rolled semis for sale, structural steel shapes, steel bars, strip, plate, and sheet, and galvanized sheets and strip. It also produces ground basic slag, blast furnace cement, slag, lime, and refractory material.

Thyssen's most important subsidiary companies are the steel producers, Deutsche Edelstahlwerke, Niederrheinische Hutte, and Phoenix-Rheinrohr.

Ilseder Hutte—Capitalization: DM140,400,000 authorized, DM140,400,000 outstanding in common stock at DM1,100 par.

Ilseder Hutte is an integrated steel company producing iron ore, pig iron, semifinished steel, billets, structural shapes, and merchant bars. Following are its principal subsidiaries:

Mannesmann A.G.—Capitalization: DM620,000,000 authorized, DM581,818,000 outstanding in common stock at DM100 par.

Mannesmann with its subsidiaries is an integrated iron and steel company, but its principal business is in raw materials, iron ore, and coal. Through its subsidiaries, Mannesmann produces coke, iron ore sinter, pig iron, and steel semis, plate, bar mill products, seamless and welded tubes, structural shapes, black, galvanized, and lead coated corrugated roofing, sheets, and a wide variety of steel consumer products. It has subsidiaries in Canada, Turkey, United States, and Brazil. The Brazilian Cía Siderúrgica Mannesmann, at Belo Horizonte, produces iron ore for use by the company in Brazil and for export.

Industrie und Handels-Aktiengesellschaft Peine
Peiner Maschinen-und Schraubenwerke A.G.
Delta Steel, Inc., Houston, Texas
American Pecco Steel Corp., Mount Prospect, Ill.

Luxembourg

The iron ore industry of Luxembourg is controlled by the two steel companies that operate there, Arbed and Rodange.

Arbed (Aciéries Réunies de Burbach-Eich-Dudelange S.A.).—Capitalization: LuxFr6,480,000,000.

Arbed is a completely integrated steel company, but it obtains its coal through associated companies. The company produces carbon and alloy steel ingots, semifinished steel, reinforcing

and merchant bars, structural shapes, sheet piling, rails, rods, plates, sheet, strip, and skelp.

Rondange (Miniere & Metallurgique de Rondage).—Rondage is an integrated steel company and operates its own iron ore mines producing ore for its own use. It produces billets, blooms, slabs, semifinished steel, reinforcing and merchant bars, structural shapes, and rails.

Norway

The Norwegian government controls a large part of the iron ore industry through majority ownership in A/S Sydvaranger and full ownership of Fosdalens Bergverks A/S and A/S Rana Gruber, Norway's three principal iron ore mines.

Christiania Spigerverk.—Capitalization: NKr22,440,000 in common stock.

Christiania Spigerverk is Norway's only integrated steel operation. It operates the State-owned Rodsin Mines, principally for its own use. The company produces carbon steel ingots, reinforcing and merchant bars, rails, wire rods, and drawn iron and steel wire products.

Sydvaranger.—The Sydvaranger plant was destroyed in World War II. A total of NKr176,500,000 was invested to restore the plant after the war; NKr35,500,000 of this came from the company's own funds, and NKr133,000,000 came from loans guaranteed and stock purchased by the Norwegian Government. However, Sydvaranger operates as a private company, governed by its own board of directors. It produces iron ore concentrate, principally for export to England.

Spain

The iron-ore mining operations in Spain are controlled by (1) Government-owned steel companies, (2) independent steel companies, and (3) by independent mining companies.

Altos Hornos de Vizcaya, S.A.—Capitalization: Pts4,453,486,000 in common stock.

Vizcaya produces pig iron, semifinished steel, reinforcing and merchant bars, structural shapes, rails, plate, sheet, and tin plate.

Compañía Andaluza de Minas, S.A.— Andaluza operates Minas del Marquesado, the largest iron mine in Spain, with technical and financial colaboration of the Compagnie de Mokta of Paris, France. The company produces iron ore for export, has a private railway spur to link the mines with the State railway network, and owns a ship-loading dock and blending yard at Almería on the Mediterranean.

Empresa Nacional Siderúrgica, S.A. (Ensidesa).—Capitalization: Pts16,800,000,000 social capital.

Ensidesa is part of a group of industries controlled by the Government through the Instituto Nacional de Industria. However, it operates in essentially the same manner as a public corporation. It is an integrated steel company and operates its own coal, iron ore, and limestone mines. It produces coke and coke chemicals, pig iron, semifinished steel, structural shapes, rails, plates, sheets, and strip.

Minera de Sierra Minera.—Capitalization: Pts84,000,000 (including Railroad).

The mines of Sierra Minera form part of an industrial empire which includes the railroad of the Sierra Minera and steel plants of Altos Hornos de Vizcaya at Sagunta. Ninety-five percent of the company is owned by Spaniards and 5 percent by Englishmen.

Sweden

Sweden's iron mining industry is divided among private concerns operating and selling iron ore on interior and export markets, and the Government - controlled Luossavaara - Kiirunavaara mining complex (LKAB).

Luossavaara-Kiirunavaara AB (LKAB).—LKAB is 96 percent owned by the Swedish Government, but is run in much the same manner as a private company. The company operates iron mines, concentrating and pelletizing plants, railroads, and ship loading facilities. Some of the profits from the operation are deposited in ore funds used to establish industry in the north of Sweden, and some are used to support research and development for the benefit of the Swedish minerals industry.

The Ställberg Mining Group.—The Ställberg Group is a privately owned business concerned exclusively with the production of iron ore in Sweden, for domestic use and for export. Idkerberg, Stripa, and Forsbo mining companies are its subsidiaries. Stallberg's capitalization is obscure.

Trafikaktiebolaget/Grängesberg - Oxelosund (TGO).—Capitalization: 5,000,000 shares authorized, 5,000,000 shares outstanding of common stock at SKr100 par.

The Grängesberg company was formed in 1896 to operate the railway system between the mining area in middle Sweden and the Baltic Sea. The company has its own railroad, export harbor, and shipping division. It operates iron ore mines in Sweden and is the operating company for the Nimba mining project (LAMCO) in Liberia, West Africa. It also owns 4 percent of LKAB.

United Kingdom

Practically the entire iron ore mining industry of the United Kingdom became the property of the Government's National Steel Corp., later changed to the British Steel Corp. (BSC), when 14 of the largest integrated iron and steel companies of Great Britain were nationalized on July 28, 1967.

The companies nationalized owned or controlled 22 integrated steel plants and 42 other iron and steel works, which together have produced about 92 percent of the crude steel in the United Kingdom. Approximately 150 small steel companies were left in the private sector. However, these companies produce principally special alloy steels and cold-worked shapes. BSC comprises the second largest steel producer in the world (1970). It produces all the usual carbon steel products and most of the alloy steel products. Its subsidiary and affiliated companies operate in most of the industrialized countries of the world.

The Nationalization Act effectively divided the iron and steel industry of the United Kingdom into public and private sectors. However, the public sector is operated and managed in essentially the same way as a privately owned concern. It was established to achieve lower costs and greater efficiency.

U.S.S.R., Czechoslovakia, and Poland

The iron ore industry of the U.S.S.R., Czechoslovakia, and Poland is owned, operated, and completely controlled by the Governments. Yet, centralized authority, planning, and operation have proved something less than satisfactory. In the Soviet Union, large mining and beneficiation combines have been established with managers that have essentially complete authority within their area of responsibility. There is no apparent direct tie between iron ore mines and the steel-producing plants. However, both are controlled by the Ministers of Heavy Industry. Iron ore mines in Czechoslovakia and Poland are heavily subsidized by the Government.

Asia

India

India's iron ore industry is divided between privately owned concerns and those owned by the Government. The privately owned concerns are further divided into those operating in the part of India excluding Goa (formerly governed by the Portuguese), and those concerns operating in Goa. India's socialistic government regulates the planning and iron ore exporting segments of the private sector to essentially the same extent as it does the activities of the Government-owned concerns. New mines are opened only under the direction of the National Mineral Development Corp. and the Government-owned States Trading Corp. is the sole exporter of all India's iron ore except that produced in Goa. Private mining concerns in Goa are allowed to engage directly in export trade, but the Government of India has set a floor price for their iron ore and levies a tax on iron ore exports.

Steelmaking concerns in both the public and private sector own and operate most of the iron ore mines that produce ore for internal use. The public sector operates iron ore mines that produce solely for export. These exporting mines do not have a direct connection with the steel companies. The iron ore mines in Goa are independent and privately owned by companies that are completely autonomous within the restrictions cited above. Iron ore mining is their principal business, but since coming under control of the Government of India, several of the larger have actively attempted to diversify into the river transport business and into the production of fertilizer and pharmaceuticals.

Hindustan Steel Ltd.—The Hindustan company is owned by the Indian Government. It manages all Government iron and steel operations under the direction of the departmental controller of prices for the Ministry of Steel, Mines, and Fuels. In its various plants it produces pig iron, and steel billets, slabs, blooms, structural shapes, bars, plate, railroad wheels and axels, light, heavy, and crane rails, hot-dipped tin sheets and pipe, and coal chemicals, and sells blast furnace and open hearth slag.

The Indian Iron and Steel Co. Ltd.—The Indian Co. is a public, fully integrated steel producer. It operates its own iron ore, coal, and limestone mines, and produces coke products, pig iron, and steel semis, merchant bars, structural shapes, rails, and sheet, and galvanized plain and corrugated sheets.

Mysore Iron and Steel Works.—The Mysore Iron and Steel Works is owned by the Government of the State of Mysore, but it is run as a private corporation. The company operates its own iron ore mines, and produces foundry pig iron, ferrosilicon, steel merchant bars, structural shapes, hoop, and strip.

Tata Iron and Steel Co. Ltd.—The Tata Co. is a public, fully integrated steel producer. It operates its own iron ore, coal, and limestone mines.

In its own and subsidiaries' plants it produces steel semis, reinforcing and merchant bars, structural shapes, rail, plate, sheet, hoop and strip, skelp, and ferroalloys.

Malaysia

The iron ore mining industry of Malaysia is owned by individual private companies and concerns incorporated under the laws of Malaysia. Eastern Mining and Metals Co. with its subsidiary, the Rompin Mining Co., Ltd., is by far the largest iron mining company. Apparently the firm's principal business is iron ore mining. Company accounts are available to shareholders only, but judging by the records of investments publicly announced, the iron mining operations of Eastern Mining and Metals Co. with its subsidiary are capitalized at more than M$50 million. Capital of the other Malaysian mining companies ranges downward from that amount to only a few thousand Malaysian dollars.

Africa

Algeria

The iron ore industry of Algeria was nationalized by decree in May 1966. The action was taken principally to assure continued operations of the properties, as competition on the world market was making operation of the Algerian iron mines progressively less profitable. The Algerian Bureau for Mineral Research and Exploration operates the properties with the help of outside consultants. Plans for a new steel mill have not yet affected the iron ore industry.

Liberia

The iron ore industry of Liberia is a partnership between Government and private industry. Government is represented on the boards of directors of the mining companies, but it does not interfere in operations. The enterprises are run by professional managers and operating companies in much the same way as are joint enterprises in the United States. The companies are integrated through iron ore mining, processing, transportation storage, and shiploading facilities.

German Liberian Mining Co. (DELIMCO).—6,600 shares authorzed, 6,270 shares outstanding of common stock at US$2,500 par. Total capitalization, US$16,500,000.

DELIMCO is owned 50 percent by the Liberian Government and 50 percent by Gewerkschaft Exploration which, in turn, is controlled by the Thyssen Group of West Germany. Bong Mining Co. manages the company's iron ore and other properties. Investments total US$83 million.

Liberia Mining Co. Ltd. is operated on an 80-year lease from the Liberian Government. It is owned 25 percent by the Government, 10 percent by the Liberian Foundation, and 65 percent by investors in the United States, of which Republic Steel Corp. is the largest. The mine and service railroad are managed by Republic Steel Corp.

Liberian American-Swedish Minerals Co. (LAMCO).—Capitalization: 1,000,000 shares class A stock owned by the Liberian Government. 1,000,000 shares class B stock, owned by Liberian Iron Ore, Ltd., which is owned 74.8 percent by the Swedish LAMCO syndicate and 25.2 percent by American, Liberian, and other shareholders.

LAMCO participates (75 percent) with Bethlehem Steel Corp.'s Liberia Bethlehem Iron Mines Co. (25 percent) in the LAMCO joint venture. Basic investments in LAMCO's Nimba mine beneficiation plant, railroad, port, and other facilities total more than $US275 million. The enterprise is managed by the Grängeberg Co. of Sweden.

National Iron Ore Co. (NIOC).—Capitalization: US$10,000,000.

NIOC is owned 50 percent by the Liberian Government, 15 percent by the Liberian Mining Co., Ltd., and 35 percent by Liberian Enterprises Ltd. The latter is the corporate vehicle for Liberian citizens' investment in the operation. The Liberian Government allocated ownership shares in Liberian Enterprises Ltd. to its citizens by county and restricted a single-family purchase to 20 of the US$100 shares. National Iron Ore Co., Ltd. property, the Mano River mine, is operated by Mine Management Associates, a private consulting concern.

Mauritania

The iron ore industry of Mauritania is centered in the Société des Mines de Fer de Mauritanie (MIFERMA). MIFERMA is a closely held operating corporation owned by the Bureau de Recherches Géologiques et Minières, the French Steel industry, British Investment Ore Ltd., Finsider SPA of Italy, and the Thyssen Group of West Germany. The Mauritanian Government owns 5 percent of the business and private French capital holds a little over 16 percent. Total investment in the mine, railroad, and shiploading dock has been reported at US$194,00,000.

Sierra Leone

Sierra Leone Development Co. Ltd. is the

sole component of the iron ore industry of Sierra Leone.

Sierra Leone Development Co. Ltd. is —Capitalization: 8,000,000 shares authorized, 6,-000,000 shares outstanding of common stock of £21 par. The William Baird Ltd. owns the remaining 5 percent. DELCO operates the Marampa iron ore mine, 52 miles of railroad, and ship loading docks.

Republic of South Africa

The iron ore industry of South Africa is controlled by the steel producers, South African Iron and Steel Corp., and African Metals Corp.

African Metals Corp. Ltd. (AMCOR)—Capitalization: R8,000,000 authorized, R7,612,500 outstanding in common stock; R800,000 authorized, R800,000 outstanding in preferred stock.

AMCOR mines iron ore, coal, and limestone and produces pig iron for sale to Japan and foundry pig iron for use in its own plant. It also produces ferroalloys although it is not an intergrated steel producer.

South African Iron and Steel Industrial Corp. Ltd. (ISCOR)—Capitalization: R55,000,000 authorized in common stock; 500,000 shares outstanding of Class A stock; 24,680,364 shares outstanding of Class B stock; 219,636 shares outstanding of preferred stock (7½ percent cumulative).

The Government of South Africa owns all of the voting stock of ISCOR. The corporation issued 7½-percent preferred shares to a small number of private owners when only 219,636 of an initial offering of 3 million was subscribed by the public.

ISCOR is run in the same manner as a privately owned corporation. The government has not interfered with the company except to restrict dividend payments to the amounts it would have received as simple interest on its investment and to insist that the price for steel products be kept at a low level.

ISCOR operates iron ore mines and produces pig iron and steel semis, reinforcing and merchant bars, structural shapes, rail, rod, plate, sheet, hot and cold-rolled coil, hoop, strip, hot-dipped tin plate, and galvanized and barbed wire.

Oceania

Australia

The older iron ore industry of Australia is operated and controlled by the steel companies. The newly developing industry in western Australia is owned by associations of several companies put together in much the same way as the joint venture companies operating in the United States and Canada. The Australian Government does not interfere with internal operations, but it established a floor on the price of iron ore sold on the export market which was later restricted and now insists on approving all export contracts.

In most instances the newly formed concerns receive financing from their parent companies as required for development in proportion to share ownership. The investment totals are not yet available.

The Broken Hill Pty. Co., Ltd.—Capitalization: 200,000,000 shares authorized, 141,765,018 shares outstanding in common stock at A$2 par.

Broken Hill is an integrated steel company which operates iron ore, coal, and limestone mines, and produces pig iron, foundry iron, steel semis, merchant and reinforcing bars, structural shapes, sheet piling, rail, rod, pipe, hot-rolled coil, hoop, strip, skelp, wire, galvanized wire, and tin plate. Broken Hill has formed the Dampier Mining Co., Ltd. to take over all its iron ore operations in Western Australia (see below).

Hamersley Iron Pty. Ltd.—Hamersley Iron is owned 54 percent by Conzinc Riotinto of Australia Ltd., 36 percent by the Kaiser Steel Corp. of the United States, and 10 percent by the Australian people. The company operates a standard gauge railroad and a deep water port. It produces iron ore solely for the export market.

Kolanooka Hills, Western Mining Corp. Ltd.—Hanna Mining Co. (25 percent) and Homestake Mining Co. (25 percent) of the United States joined Western Mining Corp. Ltd. (50 percent) in exploiting the Koolanooka Hills iron ore deposits in 1962. The joint venture first started development of the Tallering Range deposit, but shifted operations to the Koolanooka Hills because of better accessibility.

Mt. Goldsworthy Mining Associates.—Mt. Goldsworthy is owned equally by the Utah Construction and Mining Co., Consolidated Gold Fields Australia Ltd. and Cyprus Mines Corp. The company produces iron ore for export and operates a deep water port and 70 miles of railroad.

Mt. Newman Iron Ore Co., Ltd.—Mt. Newman is owned by Amax Iron Ore Corp., a wholly owned Australian subsidiary of American Metal Climax Inc. of the United States (25 percent); Mitsui C. Itoh Iron Pty. Ltd. of Japan (10 percent); Dampier Mining Co., Ltd., a subsidiary of Broken

Hill Pty. (30 percent); Colonial Sugar Refining Co. Ltd. of Australia and Selection Trust Ltd. of England through their subsidiary Pilabara Iron Ltd. (30 percent); and Seltrust Iron Ore Ltd. of the United Kingdom (5 percent). Mt. Newman properties are the iron ore mines, 260 miles of standard gauge railroad, and a deep water port. Dampier Mining Co. is responsible for the management.

Robe River Ltd.—The Robe River venture is owned by the Mineral Securities Australia group (35 percent); Cleveland-Cliffs Iron Co. of the United States through Cliffs Western Australia (30 percent); Mitsui and Company Ltd. of Japan (30 percent); and Garick Agnew Pty. Ltd. of Western Australia (5 percent). The company is to operate mines, a standard gauge railroad and a deep water port, producing iron ore, including pellets, for export by 1973.

Tasmania

Dahlia Mining Co.—(Northwest Iron Co.).—This company was formed to exploit the iron ore resources of the Savage River. Dahlia Mining Co., controlled 75 percent by Mitsubishi Shoji Kaisha and 25 percent by Sumitomo Shaji Kaisha, owns 50 percent of the project. The other 25 percent is held by the Northwest Iron Co. Ltd., a consortium of Pocantico International Corp., Cerro Corp., Pickands Mather and Co. International, and a number of Australian institutions and public companies that have equity in Pickands Mather International. Pickands Mather International manages the project.

CHAPTER 7.—EMPLOYMENT AND PRODUCTIVITY

EMPLOYMENT

The iron ore industry of the United States employs an average of 18 to 20 thousand people directly in operating jobs in mining and processing iron ore, and 8 to 10 thousand more in administrative jobs and related work. The average in operating jobs includes office and maintenance employees at the mines and mills but excludes main-office workers and sales organizations housed outside the mining districts. It includes those transporting ore from the mine to beneficiation and processing plants but excludes employees engaged in the transportation of iron ore from mine to market.

As a group, employees in the underground and open pit iron ore mines and beneficiation plants are skilled above the average of employees working in manufacturing, construction, and service industries. Most employees in iron mines operate or service highly sophisticated mechanical equipment, and the trend from underground to open pit mining has, if anything, demanded a more-highly-skilled working force. A large number of the processes which produce iron ore concentrates and agglomerates are automated, and a growing number of the processes are controlled with computers.

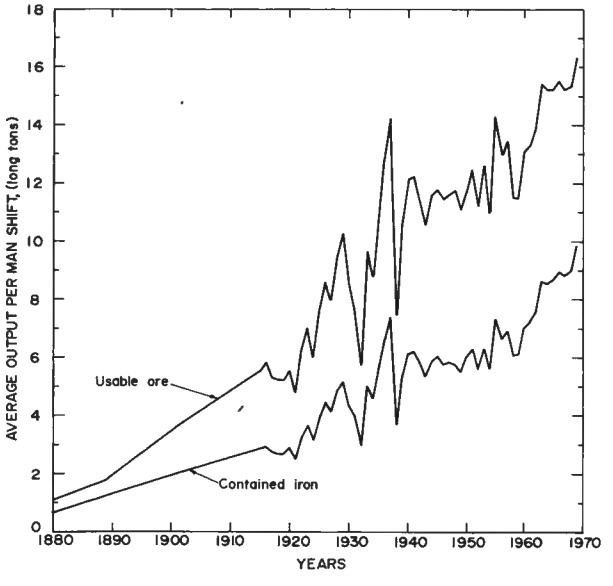

FIGURE 16.—Historical record of productivity in domestic iron ore mines.

The historical record of employment, presented in Table 35 and shown in figure 16, marks the significant changes in the iron ore mining industry. Until 1915 most of the ore was mined by manual labor and horse-drawn equipment; a large percentage of it was mined underground; and although there was very little beneficiation, the total labor force was more than twice what it is today. The application of mechanical equipment in the mines generally caused a decline in the total labor force. In beneficiation plants, however, increased mechanization and the shift from underground to open pit mining resulted in employment increases at a relatively constant rate. The labor force was relatively stable after the depression of the 1930's until the early 1950's. A steep drop in employment during the last decade was caused by the closing of underground mines and development of the taconite mining industry.

PRODUCTIVITY

Data on output per man-shift in Table 35, and also shown in figure 16, are not true records of productivity because of the efforts of most operating companies to stabilize operating crews in the Lake Superior district. During the winter months the open-pit mines in the soft ores of the Lake Superior district shut down for 4 months, coincidental with the end of the Lake Superior shipping season, but it is common practice for the mining companies to keep men working in stripping or maintenance operations. This introduced marked bias in the records of productivity from 1940 to about 1960. From 1960 on, there is less bias because the taconite mines operate year round, and the soft ore mines that close for the winter have been fewer in number.

The sharp increase in output of crude ore per man-shift since 1950 was caused by the decrease in underground mining, an increase in mechanization and the use of larger equipment. The increasing spread between the output of crude and usable ore leaves little doubt that most of the increased output was the result of the taconite operations. In the taconite mines productivity has been increased principally by better drilling and blasting practice, and hence better fragmentation, which in turn has permitted the use of larger equipment.

People working in agglomerating plants at and

near the mines have been included in the statistical records of employment since the inception of agglomeration in the Lake Superior district. Despite their addition to the labor force, the output of usable ore per man has continued an upward trend. This was made possible by larger processing plants, automation, and closer coperation between the mining and milling departments.

Eighty-five years of progress in the iron mining industry of the United States is reflected in the data on output of iron-in-ore per manshift. The increase from a little more than ½ ton of iron per manshift in the underground mines of Pennsylvania, New York, and New Jersey in 1880 to an output of about 10 tons of iron per manshift in all the domestic iron ore mines in 1970 represents an accurate record of growth rate.

Table 35.—Iron ore mine and beneficiation plant employment in the United States, 1880-1970

Year	Average number of men employed	Average output per man shift (long tons)		
		Crude ore	Usable ore	Contained iron
1880	5410	1.14	1.14	0.68
1889	15,930	1.78	1.78	NA
1902	NA	3.75	3.75	2.07
1915	30,842	5.74	5.56	2.86
1916	40,279	5.99	5.81	2.98
1917	42,067	5.48	5.34	2.75
1918	39,335	5.44	5.23	2.69
1919	35,695	5.46	5.21	2.69
1920	35,622	5.81	5.56	2.88
1921	22,928	5.10	4.79	2.50
1922	24,486	6.67	6.26	3.25
1923	28,756	7.59	7.07	3.68
1924	27,651	6.38	6.03	3.14
1925	25,472	8.13	7.63	3.97
1926	24,483	9.09	8.62	4.48
1927	24,904	8.52	8.04	4.15
1928	20,881	10.08	9.44	4.87
1929	21,811	10.83	10.06	5.17
1930	22,301	9.33	8.48	4.37
1931	16,487	8.28	7.60	3.94
1932	8,768	6.42	5.70	2.99
1933	11,598	10.98	9.66	5.01
1934	12,006	9.56	8.80	4.55
1935	10,360	12.37	10.81	5.63
1936	14,126	14.15	12.83	6.64
1937	17,836	15.70	14.26	7.39
1938	19,788	8.31	7.46	3.70
1939	21,859	11.80	10.64	5.35
1940	25,128	13.76	12.16	6.16
1941	28,587	14.25	12.22	6.22
1942	32,774	13.84	11.47	5.85
1943	33,280	12.55	10.55	5.38
1944	29,244	13.73	11.58	5.87
1945	26,777	14.22	11.78	6.04
1946	28,009	13.67	11.45	5.77
1947	29,821	14.26	11.60	5.83
1948	30,375	14.71	11.74	5.78
1949	31,493	13.73	11.07	5.54
1950	31,087	15.41	11.97	5.90
1951	34,332	16.32	12.47	6.31
1952	35,716	16.40	11.21	5.61
1953	35,301	18.94	12.57	6.31
1954	31,993	17.91	10.99	5.57
1955	29,009	23.30	14.30	7.31
1956	31,931	23.41	12.95	6.63
1957	30,887	25.03	13.51	6.91
1958	27,239	25.08	11.51	6.09
1959	28,368	19.89	11.52	6.11
1960	27,543	23.04	13.08	6.99
1961	22,710	25.79	13.29	7.22
1962	21,010	27.95	13.86	7.59
1963	18,199	32.28	15.42	8.64
1964	20,661	32.00	15.22	8.56
1965	20,773	30.90	15.24	8.69
1966	20,341	31.70	15.53	8.97
1967	19,290	33.50	15.23	8.84
1968	18,000	35.43	15.38	9.01
1969	19,000	38.55	16.33	9.84
1970	17,000	39.07	16.35	9.71

CHAPTER 8.—RESEARCH AND DEVELOPMENT

RESEARCH IN THE UNITED STATES

Research has proved the lifeblood of the U.S. iron ore industry. Practices developed in research laboratories have enabled the industry to profitably mine low-grade deposits and process them into high-grade concentrates.

Iron ore research is a continuing operation of a variety of organizations. Much developmental research is done in the mines and mills by the operating staffs. It is conducted in connection with everyday operations, and although it is not specifically categorized as research by those who do it, the technological advances achieved in this manner often are more significant than those made in more formal research organizations. Industrial iron ore research isolated from operations normally is done by research divisions of those integrated steel companies that operate iron mines. When specific problems are encountered that cannot be handled in company laboratories, arrangements are made to work through outside consultants, educational institutions, nonprofit foundations, or in Federal or State Government research laboratories. It is common practice for the larger concerns to establish pilot operations for handling a particular ore to prove equipment and processes before designing them for a commercial plant.

Cooperative research between private companies and the Government has contributed greatly to the iron ore industry. The largest project involved 22 steel companies who formed Blast Furnace Research Inc. to operate the Bureau of Mines experimental blast furnace at Bruceton, Pa., in cooperation with the Bureau. The work by this group extended through 4 years and involved expenditures of more than $6 million of private and Government funds. It is probably safe to say that more than half the advances in iron ore technology in the last two decades have been made on cooperative projects in which industry works with State and Federal researchers.

Associated industries also aid this research effort. Companies that manufacture milling and agglomerating equipment support basic and applied research on iron ore. Chemical concerns that sell flotation reagents and explosives also engage in research that benefits the iron ore industry.

Research at the state-supported mining and metallurgy laboratories in Minnesota and Michigan has been directed almost entirely to iron ore mining and processing. Iron ore beneficiation research has been an integral part of Federal Bureau of Mines programs since 1914.

U.S. Mining Companies

The Cleveland-Cliffs Iron Co.

Cleveland-Cliffs has a research laboratory and pilot plant at Ishpeming, Mich. The researchers are concerned largely with the operating problems of the Cliff properties and in finding methods to concentrate fine-grained hematite ores owned by the company in Minnesota and Michigan. The Cleveland-Cliffs staff investigated autogenous grinding before it was installed in iron ore mills in the United States, and developed better magnetic separation and flotation practices for use in the Cliffs' beneficiation plants.

The Hanna Mining Co.

Hanna Mining Co. has a pilot plant at Cooley and a research laboratory at Hibbing, Minn., which are concerned principally with operating problems of Hanna mines. The staff is enlarged at times to work on specific research applicable to resource properties that the company has under consideration for exploitation. Hanna's geologists, engineers, and metallurgists work together closely in exploring and evaluating an ore body before it is brought into production.

Pickands Mather & Co.

Pickands Mather has a research laboratory at Hibbing, Minn., which is concerned principally with the operating problems of its properties. The staff has been successful in developing methods to improve the grade of concentrate in the Erie beneficiation plant.

Reserve Mining Co.

Reserve Mining Co. has established a separate research department near its plant at Silver Bay, Minn. The principal function of this department is to conduct basic and applied research on iron ore processing, although it is consulted on the day-to-day operational problems of the nearby con-

centrating and agglomerating plants. The company's mining research is done at its Peter Mitchell mine by the operating staff. They have been concerned principally with developing drilling and blasting technology to improve fragmentation.

U.S. Steel Corp.

U.S. Steel Corp., has an iron ore research laboratory and pilot plant at Coleraine, Minn., and a comprehensive research establishment and experimental blast furnace at Monroeville, Pa. The laboratories at Coleraine are engaged almost entirely in applied iron ore research and beneficiation plant operating problems. Iron ore work at Monroeville is only a small part of a large research complex. Most of it is basic. The corporation's Pilotac concentrating plant in Minnesota has been operating since 1953 as a taconite research facility.

Practically all the integrated steel companies in the United States have some type of research laboratory. The following are especially active in research applicable to the iron ore industry: (1) Bethlehem Steel Corp., Homer Research Laboratory, Bethlehem, Pa., (2) Republic Steel Corp., Research Center, Cleveland, Ohio, and (3) Inland Steel Co., Research Department, Chicago, Ill.

Nonprofit Research Organizations

Battelle Memorial Institute, Illinois Institute of Technology Research Institute, Stanford Research Institute, Colorado School of Mines Research Institute, and Mellon Institute and others have been retained at times by the iron ore industry to make independent studies of iron ore marketing, concentration, agglomeration, and reduction. These organizations have competent staffs and present a useful mechanism by which the iron ore industry can obtain technical and economic data collectively.

Equipment Companies

Allis Chalmers Co., Milwaukee, Wis., Dravo Corp., Pittsburgh, Pa., Midrex Divison, Midland-Ross Corp., Toledo, Ohio, and McDowell-Wellman Engineering Co., Cleveland, Ohio, have been unusually active in the last decade in research on iron ore beneficiating, especially agglomerating processes.

Government-Sponsored Research

Federal Bureau of Mines

Most of the Bureau's research on iron ore has been done in its laboratories at Tuscaloosa, Ala. and at Twin Cities (Minneapolis), Minn. The laboratories at the two research centers have been responsible for the inception and development of many beneficiating processes involving hydro- and pyro-metallurgical schemes. A large number of patents have been granted on the work accomplished and many reports published. Prereduction of iron ore has been studied by both laboratories in recent years. Its research on blast furnace operation was conducted first at Minneapolis, then at Pitsburgh, and finally at Bruceton, Pa. The experimental furnace at Bruceton has not been used since early 1967.

Institute of Mineral Research, Michigan Technological University, Houghton, Mich.

The Institute of Mineral Research was established in 1955 specifically to conduct research leading to development of the iron ore resources of the State of Michigan. This has been its principal function.

Mines Experiment Station, University of Minnesota, Minneapolis, Minn.

Research on iron ore mining, concentrating, and agglomeration has been the principal activity of the Mines Experiment Station since its inception. Processes used to exploit taconite ores were first tested in its laboratories.

RESEARCH IN FOREIGN COUNTRIES

Industrial research on iron ore in foreign countries has been conducted by the iron ore and iron and steel industries in about the same maner as in the United States, except that in Western Europe, associations of steel companies and associated enterprises support cooperative research on a continuing basis. Engineering staffs at the mines and mills constantly research better methods of operation. Studies on agglomerating methods are conducted at the steel mills in conjunction with the sintering operations. Equipment and chemical companies in foreign countries have research divisions, as do those in the United States. The basic research on iron ore mining and processing in foreign countries is done at educational institutions and in Government-sponsored laboratories. There are few independent research foundations in foreign countries and none in Canada, similar to those operating in the United States, that devote full attention to iron ore.

Canada

Apart from the research at operating properties, iron ore research in Canada is conducted principally by the Department of Mines Technical

Survey, Mines Branch of Canada, at Ottawa. Ontario Research Foundation, Toronto, Ontario—a nonprofit research organization originally founded by industry and Government funds, this organization engages in research on contract for industry, Government departments, and its own account. Of primary interest is the development of Ontario's natural resources (including iron ore). Revenues are derived largely from sponsored research.

Europe

Much of the iron ore research in Western Europe is done at Institut de Recherches de la Sidérugies (IRSID), Maizières les-Metz, France, which has been supported by the European Coal and Steel Community, and by the iron and steel industries of France and West Germany.

Research at IRSID ranges from fundamental iron ore mineralogy and petrography to ore dressing, concentration, agglomeration, and reduction. The staff also does some research in steelmaking, but most of the research on physical properties of iron and steel is done at the IRSID Laboratories, Saint-Germain-en-Laye.

Belgium, Centre National de Recherches Metallurgiques, Liège

The Centre National is supported by Benelux iron and steel and nonferrous metals companies and by various associated enterprises. As its name implies, the work is devoted to all types of metallurgy, from extraction to physical processes. A large part of it is ferrous metallurgy. The Centre operates an experimental blast furnace directed by an international committee. This part of the operation has been supported partly by the European Coal and Steel Company.

Federal Republic of Germany, Max Planck Institute, Düsseldorf

Research at the Max Planck Institute is similar to that conducted in the nonprofit research foundations of the United States, but in general, the studies are directed to steel and more to basic than to applied research. The institute is supported jointly by the iron and steel industry and Government.

Sweden, The Metallurgical Research Plant, Lulea

Research here is conducted in close cooperation with the steelmaking and mining companies of Sweden. The plant's laboratories are equipped for pilot-scale investigations and operate as a center for translating coordinated Swedish research effort into metallurgical processes. Most work is of common interest to the iron and steel industry, but programs of specific types are undertaken for private companies. Well known projects include the Eketorp-Vallak method of ironmaking and the WORCA continuous steelmaking method.

The Granges Co., through its Granges Steel Division, has a modern and well equipped Mineral Process Department at Stråssa which conducts research for all iron operations. The Grancold pelletizing process was developed and carried through semi-commercial operation here. Contract research on ores from foreign sources is also a function of the laboratories.

U.S.S.R., Central Research Institute of Iron and Steel

Judging by the reports published by the Central Research Institute, the work there covers as wide a range as that in the research institutions of the United States. However, emphasis is on applied rather than basic research. Many of the researchers seek refinement of existing operations. Their reports serve to disseminate information on superior operating practice throughout the iron and steel industry of the U.S.S.R.

United Kingdom, British Steel Corporation (BSC)

Since nationalization of the iron and steel industry, BSC assumed control of research operations formerly conducted by the British Iron and Steel Research Association (BISRA). Reorganization resulted in research and development departments being formed in each of the corporation's six divisions, and a separate Corporate Laboratories (BISRA) group. The head office of the corporation maintains overall coordination of efforts through a director of research and development. Contracts and grants are given also to various universities and other research organizations. Joint research groups are established with private company laboratories to round out the research effort.

Laboratories of particular interest in studies on iron ore and ironmaking are located at London, Teesside, and Rotherham. The London laboratories are primarily concerned with fundamental research, and the formulation of standards and specifications.

Corporate Laboratories (BSC), Teesside

Corporate Laboratories (BSC) is operated by the corporation for research on ore preparation. Problems involving the use of ores are studied, and new materials are examined. Studies of sinter and pellet technology, which are correlated with those

on blast furnace performance, are part of the program.

Swinden Laboratories (BSC), Rotherham

Research and development departments of the General Steels Division and Special Steels Division are located here. These are the largest of the BSC laboratories, and carry out research in diverse areas of study which are of interest in the two divisions.

Asia

India, National Metallurgical Research Laboratory

India's National Research Laboratory is concerned principally with developing operating practices that will apply to beneficiation and concentration of the variety of iron ores produced in India Basic research apparently is a small part of the overall program.

Japan, Research Institute of Mineral Dressing and Metallurgy, Tohuhu University, Sendia City

Laboratory research is conducted in relation to both the theory and practice of iron and steelmaking. Domestic and foreign ores are tested.

Philippines, Bureau of Mines, Manila

The Bureau of Mines maintains central and regional laboratories to develop processes for domestic ores. Much work has been done on low-grade beach sands to recover iron and other metal values.

CHAPTER 9.—LEGISLATION AND GOVERNMENT PROGRAMS

UNITED STATES

Legislation

Federal Government regulations imposed on the iron ore industry have been minimal; only those laws and regulations applicable to all minerals are significant. The latter comprise the Mining and Mineral Leasing Acts which govern exploration, development, and extracton of metalliferous minerals on Federal lands. The first general mining law, the act of 1866 (14 Stat. 251), and changes in the act of 1872 (17 Stat. 91), incorporated three fundamental principles: (1) the policy of free access to all unoccupied public mineral lands for exploration; (2) the recognition of rights on public lands previously acquired under local rules; and (3) the right to obtain titles to public lands on the basis of mineral rights after certain procedures had been complied with. Subsequent legislation has provided certain changes and clarified some provisions of the original act (*3-6*). Procedures for unpatented and patented claims have been summarized in a previous Bureau publication (*2*).

The Bureau of Land Management (BLM), under the Secretary of the Interior, is charged with the administration of Federal lands. One BLM objective is to encourage development of mineral resources on public lands. It also administers mining and mineral leasing on lands in the public domain on which mineral rights have been reserved to public ownership, and on submerged lands of the Outer Continental Shelf.

State-owned or State-controlled mineral lands are regulated by State laws which are generally similar to the Federal laws. Lands normally under State control include public school and university properties, swamps and lakebeds, and tax-forfeit property.

Privately owned mineral lands are regulated by the laws of individual States. Prospecting or the development of minerals on private property must be done within the framework of laws relating to property titles, conveyances, leases, and contracts of the State in which the property is located. Private rights pertaining to mining are restricted to some extent under State and Federal statutes governing zoning, subsidence, health, and safety.

Taxation

Federal taxes levied on producers of iron ore are essentially the same as those levied on any corporation or individual engaged in mining operations. The Federal income tax is by far the most significant from a standpoint of revenue. Because most iron ore is produced by corporations, the corporate income tax is of major concern to the iron mining industry.

Normally corporations are subject to a tax on income with special provisions applying to income derived from exploiting mineral deposits. A depletion allowance is authorized for iron ore and for other specified minerals in recognition of the declining values of a mineral deposit as ore is removed. Under the Internal Revenue Code of 1954, for income tax purposes, the base capital investment in an iron ore property may be recovered tax-free as the ore is removed. This can be done on either a cost-depletion basis using a reasonable useful-life period for the deposit, or on a percentage-depletion basis computed as a percentage of gross income from the property, but not exceeding 50 percent of net income. The Tax Reform Act of 1969 established the iron ore depletion rate at 15 percent for domestic mines and 14 percent for foreign mines.

State and local taxes, for which iron ore producers are liable, vary widely. Some states levy income taxes on corporate profit from iron mining and others levy franchise, property, or severance tax on iron ore producers.

Iron ore taxation in Minnesota has been complicated by the different types of ores, treatment of low-grade taconite ores, and by ownership and royalty regulations (*6, 8*). An amendment to the State constitution adopted in 1964, The Taconite Amendment, guaranteed that taxes on companies producing usable ore from low-grade iron material would not be increased above the general corporate level for a period of 25 years. Tax laws were revised in Michigan in 1964 to give tax relief to companies producing pellets from all iron ore mined underground and not from low-grade ores exclusively. Wisconsin modified its taxation of low-grade ores in 1967 to encourage pellet production from the State's taconite-type material.

Government Programs

Export-Import Bank Programs

The Export-Import Bank of the United States operates as an independent corporate agency of the U.S. Government to assist and facilitate the overseas trade of the United States. Founded over 35 years ago, it presently operates under the Export-Import Bank Act of 1945, as amended by various public laws through 1969. Under authority granted by that act, much of the U.S. equipment needed in the development and exploitation of foreign iron ore deposits, as well as replacement equipment, has been financed under some phase of the Bank's program.

Direct Export-Import Bank credits have been extended for exploitation of iron ore deposits in Brazil, Chile, Liberia, Peru, and Venezuela. Some of these were as follows: (1) Cía Vale do Rio Doce, S.A., US$61.7 million between 1942 and 1969 to deveop high-grade deposits in Minas Gerais, Brazil; (2) Cía de Acero del Pacifico, S.A., US$15.6 million in 1960 to assist in developing the Algarrobo iron mines in Atacama, Chile; (3) the Liberian American-Swedish Minerals Co., US$57.6 million in 1960 and 1965 to develop the Nimba Mountain deposits in Liberia; (4) Marcona Mining Co., US$48.1 million between 1953 and 1969 to develop iron deposits near San Juan, Peru; (5) Orinoco Mining Co., US$50 million authorized in 1969 to assist in financing a plant for producing high-iron briquets from Cerro Bolivar iron ore in Venezuela.

Indian Lands

Indian lands, both tribal and those owned by individuals, are considered private and must be treated as such. Prior to entry or exploration on Indian lands a walk-out permit, or a permit to prospect, must be obtained from the owner.

Two acts of Congress, the Act of March 3, 1909 (35 Stat. 783; 25 U.S.C. 396), and the Act of May 11, 1938 (52 Stat. 347; 25 U.S.C. 396 a-f) authorized the leasing of Indian lands for mining. Special acts also have been enacted that affect leasing on certain Indian reservations. Exploration for and mining of iron ore has been done on some of the Western Indian reservations. The Federal Government's interest is not proprietary, as with public lands, but as the guardian of Indian owners. Acting through the Secretary of the Interior, it must approve any lease agreements made by them. The Government also has an obligation in supervision of regulations and operations during the term of the lease.

Government Loan Program

The Defense Minerals Exploration Admin. (DMEA) was created in 1951 under the authority of the Defense Production Act of 1950 to promote exploration and development of domestic sources of strategic and critical metals and minerals. Public Law 85-701, enacted in 1958, established the Office of Minerals Exploration (OME) in the Geological Survey of the Department of the Interior. OME replaced DMEA and assumed its functions and obligations. Federal assistance under OME for iron ore exploration was authorized in 1961. Under this program Government contributions may be up to 50 percent of total allowable costs. Applications acceptable to OME must meet specified requirements, such as a reasonable probability of a significant discovery of ore, and inability of the applicant to raise the necessary funds on reasonable terms from commercial sources.

Import Duties

There has been no U.S. import duty on iron ore, including manganiferous iron ore containing not more than 10 percent manganese, for over 50 years. Iron ore was placed on the free list in the Tariff Act of 1913, and presently comes under the provisions of paragraph 1700 of the Tariff Act of 1930. Trade-agreement concessions binding iron ore on the U.S. free list were made under the General Agreement on Tariffs and Trade at Geneva, Switzerland, effective Jan. 1, 1948, at Annecy, France, effective Apr. 30, 1950, and in a supplemental bilateral trade agreement with Venezuela, effective Oct. 11, 1952.

The U.S. Tariff Commission conducted public hearings in 1959 and 1960 to determine if iron ore imports were injurious to the domestic iron ore industry. Based on the 1960 hearings, the Commission decided that no serious injury had resulted from the imports. However, several bills have been introduced in the Congress since that time to give import tariff protection to the U.S. iron ore producers. No legislative action had resulted by March 1971.

Public Services

The Bureau of Mines issues a number of periodical and nonperiodical publications directly and indirectly concerned with iron ore. These include (1) Mineral Industry Surveys, prepared

monthly and annually; (2) Minerals Yearbook, an annual publication in three volumes, containing a chapter on iron ore in Volume I, limited iron ore coverage in Volume III on State industries, and international mineral industries information in Volume IV; (3) Mineral Trade Notes, a monthly publication covering worldwide news notes on all minerals; (4) Commodity Data Summaries, issued each January, containing a condensed preliminary report on iron ore for previous year; and (5) Reports of Investigations and Information Circulars concerning iron ore, published at irregular intervals. These latter publications cover all phases of the Bureau's research programs. Mineral Facts and Problems, a comprehensive reference with individual commodity chapters, is published by the Bureau of Mines at about 5-year intervals. The Bureau also has cooperated with the Geological Survey, State agencies, and the United Nations on many iron projects and in the preparation of publications concerning iron ore.

In 1965 Congress passed the Solid Waste Disposal Act, which vested responsibility for Federal efforts to control wastes of mineral origin in the Bureau of Mines. Under this act problems associated with solid wastes are being studied in Government laboratories and, under contract, in industry, university, and other institutional research laboratories. Results of the studies are available in various publications and contract reports.

Economic and resource studies and technical research programs are carried out by the Mineral Resources, Mining Research, and Metallurgy Research groups in Bureau field offices and research centers located in several States from coast to coast. Occasionaly, cooperative agreements for technical research on iron ore are made with universities, industrial companies, and State agencies. For example, the Bureau operated an experimental blast furnace at Bruceton, Pa., from 1962 to 1967 in cooperation with 22 iron- and steelmakers. During this time, different types of iron ore were fed to the furnace under varying operating conditions and a number of reports were published on the results. The Twin Cities, Minn. Research Center and Minerals Resource Office is the center for most of the Bureau's work on iron ore, although iron ore-related projects are conducted at other locations. The results of all Bureau projects are available to the public when completed except those classified for national security reasons. New publications are listed in New Publications—Bureau of Mines, issued monthly, and those of general interest are usually publicized by press releases. A statistical section within the Bureau collects and disseminates the data concerning production and consumption of iron ore not normally collected by other organizations.

Special Bureau of Mines publications are for sale by the Superintendent of Documents which list all Bureau Publications and outside journal articles.

Mine Health and Safety

Workers' health and safety in mining and processing iron ore is served by the work of the Bureau of Mines, the Public Health Service of the Department of Health, Education and Welfare, and the Department of Labor.

The Bureau of Mines promoted health and safety in noncoal mines only through research and operator education and training until July 31, 1970, when Public Law 89-577 gave the Bureau the responsibility for periodic inspections and the authority to enforce safety regulations in iron ore mines.

Safety has been improved in iron ore mines and mills by cooperative efforts of the mine supervisors and workers, State safety inspectors, and Federal agencies. The record is shown in tables 36 and 37.

FOREIGN MINING LAWS

A summary of the mining laws of the important mineral producing countries of the free world was published in 1962 (*3*) and a five-volume revision of this study is currently in preparation. (*4-6*).

The significant legislation enacted by the major iron ore producing countries that pertains to exploration and development of iron ore follows:

North America

Canada

In general, the Canadian Provincial Governments hold legal title to and administer Crown (public) lands in the respective provinces, except for Indian reserves and National Parks. The mineral rights of these latter areas, the Yukon Territory, the Northwest Territories, islands of the Hudson Bay, and lands under Canada's continental shelves are vested in and administered by the Dominion Government. Development of minerals on Indian lands must be done with consent of the owners. National Parks are closed to mining except for claims existing prior to designation of the particular land area as a park. Mineral rights are now granted independently from surface rights in all parts of Canada (*1, 8*).

The Yukon Quartz Mining Act regulates iron exploration in the Yukon Territory, and the Ca-

Table 36.—Injury experience, employment, and worktime data on iron ore mines, 1931-70

Year	Average men working daily	Average days active	Man-days worked (Thousands)	No. of Injuries		Injuries per million man-hours
				fatal	Non-Fatal	
1931	21,786	202	4,408	28	774	20.50
1932	11,954	148	1,775	7	264	17.03
1933	13,954	142	1,982	12	334	20.62
1934	15,477	195	3,013	16	485	20.78
1935	14,041	219	3,077	22	440	18.72
1936	18,592	232	4,318	29	868	25.86
1937	22,957	249	5,717	33	1,383	30.84
1938	18,006	197	3,556	20	456	16.69
1939	19,769	225	4,451	23	602	17.51
1940	23,250	243	5,639	35	853	19.63
1941	25,870	265	6,848	47	1,220	23.08
1942	28,956	288	8,328	56	1,579	24.41
1943	30,058	290	8,724	48	1,742	25.57
1944	25,852	282	7,300	39	1,412	24.78
1945	23,443	286	6,696	36	1,326	25.33
1946	24,723	227	5,604	25	1,206	27.32
1947	26,478	273	7,239	36	1,403	24.74
1948	27,116	287	7,786	34	1,440	23.59
1949	27,792	249	6,907	21	1,158	21.27
1950	27,686	268	7,407	23	1,126	19.34
1951	30,576	276	8,446	33	1,264	19.10
1952	31,802	248	7,880	28	1,066	17.28
1953	30,862	270	8,335	19	1,131	17.20
1954	27,840	220	6,132	14	713	14.78
1955	24,954	245	6,105	15	776	16.17
1956	26,817	234	6,281	19	723	14.73
1957	25,669	252	6,480	13	617	12.13
1958	21,382	206	4,411	14	432	12.61
1959	22,099	179	3,966	14	482	15.59
1960	21,170	242	5,131	16	610	15.21
1961	17,251	224	3,868	10	449	14.79
1962	16,165	234	3,776	9	453	15.16
1963	13,353	251	3,357	10	402	15.21
1964	14,189	258	3,659	12	452	15.76
1965	14,439	273	3,942	5	510	16.22
1966	14,056	277	3,898	13	553	18.05
1967	12,772	282	3,600	11	478	16.94
1968	11,890	285	3,415	7	463	17.16
1969	11,477	274	3,141	6	436	17.54
1970	10,900	295	3,170	8	535	21.05

nadian Mining Regulations (1961) as amended apply to operations in the Northwest Territories and to all lands forming a part of Canada not within a province or the Yukon Territory. Provincial mining laws and regulations of the individual provinces govern the remainder.

The Government Organization Act (1966) resulted in the formation of the Department of Energy, Mines, and Resources, which replaced the Department of Mines and Technical Surveys and assumed responsibility for national policies and programs with respect to minerals, energy, water, and other resources. The Department of Indian Affairs and Northern Development replaced the Department of Northern Affairs and National Resources, and exercises powers related to conservation, mineral rights, operating practices, mining taxation and royalties in the Northwest Territories and the Yukon Territory, and also National Parks and Indian reserves.

Under Canadian Federal Income Tax Regulations, operators of metalliferous mines are granted a 33⅓-percent depletion allowance for a mine's production period, and income from a new mine may be tax-exempt for a 3-year period. Assets commonly used in mining, such as roads, machinery, and mine shafts, are separted into classes which, for tax purposes, carry various deprecia-

Table 37.—Injury experience, employment, and worktime data on iron ore mills, 1944-70

Year	Average men working daily	Average days active	Man-days worked (Thousands)	No. of Injuries		Injuries per million man-hours
				Fatal	Non-Fatal	
1944	3,384	258	874	3	97	14.13
1945	3,283	261	856	1	134	19.43
1946	3,286	190	624	1	67	13.35
1947	3,343	245	820	2	86	13.21
1948	3,259	267	871	—	101	14.35
1949	3,701	215	794	3	96	15.86
1950	3,401	239	814	3	74	11.73
1951	3,756	250	937	—	69	9.09
1952	3,914	222	869	—	54	7.67
1953	4,439	244	1,083	2	88	10.32
1954	4,153	226	939	3	80	10.96
1955	4,055	258	1,044	2	87	10.62
1956	5,114	241	1,231	1	92	9.36
1957	5,218	262	1,367	1	67	6.18
1958	5,857	246	1,441	2	60	5.37
1959	6,324	196	1,240	1	56	5.68
1960	6,413	258	1,653	—	79	5.93
1961	5,515	266	1,468	3	65	5.77
1962	4,868	283	1,376	3	91	8.45
1963	4,856	287	1,392	—	65	5.81
1964	5,534	293	1,622	1	103	8.03
1965	6,334	288	1,823	1	121	8.33
1966	6,293	299	1,881	3	117	7.95
1967	6,137	305	1,875	1	149	9.98
1968	6,579	321	2,129	—	135	7.91
1969	7,169	304	2,177	2	150	8.71
1970	6,600	334	2,203	4	162	9.41

tion allowances ranging up to 100 percent annually.

Mining legislation enacted by the various Provinces is similar, in that each Province has provided for a department to administer the various acts and regulations pertaining to mineral rights and mining. Mineral taxation and royalties and safety regulations have been provided for in legislation enacted by each Province.

Mexico

The mining laws of Mexico had their origin in the legal system of Spain. However, since the independence of Mexico in 1821 a number of changes have been promulgated, and the constitution of Feb. 5, 1917, established a base for present-day legislation. Article 27 of this constitution proclaimed Government ownership of minerals but authorized concessions for exploitation to individuals and to qualified companies, subject to certain regulations.

The Mining Law of 1930 defined and outlined conditions for exploitation of minerals, with preference given to Mexican nationals. The Mining Law of 1961 was passed to increase regulation of Mexican natural resources; it severely restricted ownership by other than Mexican nationals or by companies not controlled by Mexican capital. Iron ore is now mined exclusively by Mexican companies and essentially all is used in Mexican steel plants. Ore can be exported only with Government permission, and, because of limited resources the present policy is to reserve the nation's iron ore output for domestic consumption.

South America

Bolivia

The Code of Mines, D.S. No. 07148 of May 7, 1965, governs mining in Bolivia. Under this code all minerals are controlled by the State, and, as with most other minerals, a right to mine iron ore is obtained only from the State in the form of a concession issued under the code.

Foreign individuals or companies domiciled in Bolivia may obtain concessions, but their legal status must be acknowledged before the concession is valid.

The Department of Mines operates in an administrative capacity and advises a Superintendent of Mines in each of the nine States. The superintendents are authorized to grant mineral exploration and exploitation concessions, and rule on related matters.

A National Council of Mines, as an advisory organization, assists the Executive Power in national mining policy questions. The Executive Power may enter into contracts for mineral development by declaring certain areas to be under fiscal reserves. Under these conditions exploitation is governed by special laws.

To obtain a mineral land exploration or exploitation concession, procedures as outlined in the Code must be followed. Aerial surveys are under State jurisdiction. Applications to make aerial mineral surveys must be submitted to the Ministry of Mines. Prospecting or minor preliminary work in seeking minerals may be carried on by any person on free land, but the amount of digging permitted is limited.

Exploration or exploitation concessions must be activated within 6 months after approval, and there must be no interruption exceeding 6 months after the start of activities. The holder must submit semiannual reports. An exploitation concession gives the grantee exclusive right to the minerals covered that may be obtained within his concession. The concessions and rights may be transferred or leased.

Bolivian mines are classified as large, medium, and small. Large mines are operated by the State. Medium mines are operated by private companies which must satisfy minimum production rates but may sell to a buyer of their choice. All others are in the small category, and are subject to restrictions on sales.

Brazil

A new mining code was put into effect in Brazil by Decree-Law 227, of Feb. 28, 1967, amended in part by Decree-Laws 318 of Mar. 14, 1967, and 330 of Sept. 13, 1967. This clarified some of the confusion surrounding the older and conflicting provisions of the Mining Code (Decree-Law 1,985 of 1940) and laws of earlier dates. Iron ore and other minerals except liquid fuels, fissionable materials and natural gas are subject to the mining code. Basically, the title of all mineral deposits belongs to the Government. General geological reconnaissance is not limited, but a prospecting permit must be obtained for detailed examination of an area for specific minerals, and development is permitted only under authorization and concession. Once the right to develop a prospect is granted, the holder of the right must proceed with the Government approved plans or run the risk of having his lease revoked and the rights granted revert to the Government. The 1967 code allows a foreign national to participate in the development of mineral deposits if he is a member of a "min-

ing concern" domiciled in Brazil. The "concern," defined as a Brazilian firm or association or corporation, must have Government authorization to operate. This is granted by the Minister of Mines and Energy.

Surveillance of all prospecting and mining operations in Brazil for conservation and safety purposes is a function of the National Department of Mineral Production.

Chile

Mineral deposits regardless of surface ownership are the property of the State. Mining control is based on Decree Law 488 of Aug. 24, 1932; the regulations are Decree 2228 of Dec. 21, 1932. Concessions are granted to prospect for minerals on open lands, but permission of the occupant is required to enter cultivated or enclosed tracts. An exclusive exploration concession can be obtained only by submitting a detailed application, complete with measurements and boundaries of the surface area to be explored, minerals sought, and the name of surface owner, and by paying a fee based on size of the area. The concession is granted only after publication of the request and in the absence of any objection. However, objections may be overruled by the Government. Mining concessions are entitled to certain easements from the surface owner to facilitate mining operations, but surface owners must be compensated for damage.

Mining corporations and partnerships are subject to taxation under the Income Tax Law and to a yearly license fee, the amount of which depends on the size of the concession.

Companies producing more than 75,000 metric tons of blister copper annually in Chile were classified by the Government as "gran minera" or large-scale mining companies under a 1966 mining law. As such they were subject to a special taxation law. One foreign iron ore producer was placed in this category for tax purposes, as "gran mineria" became exempt from the usual requirement of having to return all foreign earnings to Chile. The announced nationalization of two major copper producers in 1969 leaves the future of the iron ore producers unclear.

Peru

The Mining Code established by Decree Law 11,357, May 12, 1950, forms the basic Peruvian mineral law. All mines and minerals are the property of the State, with surface rights to land separate from the estate in minerals underground. Mining is open to foreign and domestic persons, with the exception of certain Government officials, and to corporations. However, the law prohibits operations of mines by foreigners within 50 kilometers of the frontier without special Government permission.

Concessions are issued for the right of exploration and exploitation, and must be registered. Exploration concessions are valid for 5 years and may range in size from 1 to 1,000 hectares. The number of concessions granted is not limited but the areas held are taxed depending on size. A concession may be forfeited for failure to pay taxes for two consecutive years. Taxes are levied on net income from mineral production. However, to encourage general development, royalty payments amounting to a specified percentage of the profits may be substituted for taxes in some instances.

Since 1965 a number of laws affecting the mining industry have been passed. Some have effectively increased the Government's income from mining operations, while others have sought to attract mining capital by offering certain tax advantages, including rapid depreciation. Decree Law 17,527, published Mar. 25, 1969, established and organized a Ministry of Energy and Mines. This ministry has taken over the functions of formulating and directing the country's mineral resources.

Venezuela

The Mining Law of Dec. 28, 1944, and regulations of the same date govern the development of mineral deposits in Venezuela. Theoretically, each state of the Venezuelan Union is the owner of mineral deposits within its boundaries. However, under the constitution, the national administration has full control, and the states are prohibited from enacting conflicting legislation. The Ministry of Mines and Hydrocarbons of the national administration is charged with mineral resource regulation.

Concession regulations are liberal, and in general any legally competent person, including aliens, may explore for minerals on unleased public lands after giving written notice to the Ministry of the intention to do so. However, concessionaires not domiciled in Veneuela and foreign companies must comply with special regulations.

Exclusive exploration permits, limited to 2,000 hectares each, may be obtained, although not more than five such permits are granted to any one applicant. The permits are valid for 2 years, during which time annual surface taxes must be paid. Mining claims may be filed within this 2-year period, and after the claims are approved for a concession by the Ministry, mining operations

must begin within 5 years for veins or strata, and within 3 years for alluvial deposits. Operations are subject to a number of regulations as outlined by the Ministry. Title to mining concessions may be transferred after the Ministry is notified. Claim concessions may be terminated by the Ministry for failure to pay taxes, for failure to begin operations, and for suspension of operations for more than 2 consecutive years in veins or strata, or 1 year in alluvial deposits.

Certain reserve zones may be established by decree of the Federal Executive; then the normal procedure for filing claims is replaced by concessions granted at the Executive's discretion.

A mineral production tax may be imposed. The income tax law of July 26, 1955, continued a principle that the State must receive half of the net profit derived from natural resources. Additional income taxes may be levied. However, if net profits are less than 10 percent of invested capital, the income tax is not imposed. A cost-depletion-allowance deduction (as opposed to percentage depletion) is granted mining companies. Materials and equipment necessary to operate mines and beneficiation plants may be imported duty free.

Iron ore is mined in Venezuela chiefly by the Orinoco Mining Co., a subsidiary of United States Steel Corp., and Iron Mines Co. of Venezuela, a subsidiary of Bethlehem Steel Co. Both operate in the State of Bolivar under special concession agreements.

Asia

India

The Mines and Minerals (Regulation and Development) Act of 1948 (No. L111), authorized the Central Government to issue implementing rules. As a result the Mineral Concession Rules of 1949 were issued, followed by the Mines and Minerals (Regulation and Development) Act of 1957. Some additional rules have been promulgated since that date. After independence, the Constitution gave the mineral rights previously vested in the rulers of the princely States to the reorganized States or to the Central Government. In other areas, some private ownership may remain, but generally, minerals are the property of the Central and State Governments.

The Mineral Concession Rules of 1949, modified by the Mines and Minerals Act of 1957, regulate the granting of prospecting licenses and mining leases by the State governments for most minerals. Prospecting licenses for other than Indian Nationals must be approved by the Central Government. Licenses for specific minerals including iron ore may be granted or renewed only with Central Government consent.

Mining leases are granted by the State governments for aliens only with approval of the Central Government, and only to holders of a certificate of approval or a valid prospecting license. Leases are limited in area to not more than 10 square miles for any one mineral or group in a particular State. Iron ore leases may not exceed 30 years, but are subject to one renewal at the option of the lessee. Certain conditions must be followed as set forth for the holder of a lease in the Mines Act of 1952. Any breach of the terms subjects the lessee to forfeiture if not corrected within specified time limits. The Central Government can cancel any mining right under the amendment of Apr. 27, 1955, to Article 31A of the Constitution.

Rent on land covered by a prospecting license is fixed by the State Government. Rents are also established by the State Government for exploitation periods, and may vary with the circumstances. Royalties are paid at rates specified in the 1957 act.

Malaysia

Five of the federated States of Malaysia produce significant quantities of iron ore. The States are responsible for granting mining rights, but executive control rests with the Federal Government. The individual State rulers can grant land in perpetual lease, but normally leasing is for a specified time. Mineral ownership is separate from title to the surface, and the State Governments may condemn alienated land for mineral leasing. However, extensive land areas designated Malay Reservations, have been reserved for ownership by native Malays. The Mining Enactment of 1928, agreed on by the four Federated Malay States, provides three types of prospecting rights. One applies to alienated lands, and allows the proprietor or an authorized person to prospect by giving 1 week's notice to a warden of mines. The second provides for prospecting licenses; the third, for prospecting permits. A permit authorizes prospecting but conveys no right to a mining lease, while the holder of a prospecting license ordinarily has a prior right to choose land for a mining lease from State-owned land included in his license area. The terms and conditions for leases differ among the States, but are usually granted for 21-year periods with renewal rights. For non-oil leases the holder must agree to pay rents and other fees, maintain boundry markers, start mining operations within 1 year, and keep records and file re-

ports, among other requirements. Under the 1957 Constitution, the Federal Government may take and dispose of State lands when necessary for Federal purposes. The right to locate a mining claim is based on discovery and registration within certain time limits. The application for lease must be filed within 4 years. After the lease has been granted, the holder may exploit the minerals specified, subject to payments of rentals, royalties, and taxes as levied.

The Corporation Law which formerly prohibited a corporation from investing in a similar company was modified by the Republic Act 5,167, approved Aug. 4, 1967. This law gave domestic or foreign mining corporations the right to own up to 40 percent of a similar corporation.

Philippines

The Philippine Constitution of 1935 proclaimed that all mineral lands of the public domain and all waters, minerals, coal, mineral oils, and sources of potential energy belong to the State. The Commonwealth Act No. 137 of 1936 (The Mining Act), governs the disposition of minerals not specifically provided for in other legislation. These laws, together with the Philippine Bill (Act of the U.S. Congress of July 1, 1902) which covers mineral claims registered before November 15, 1935, form the basis of iron mining regulations.

The administration and regulation of Philippine mineral lands resembles U.S. procedures. The Director of the Philippine Bureau of Mines controls the minerals and mineral lands. Regulations have been established to foster development, conservation, and safety. Exploitation, development, and utilization of natural resources are limited to Philippine citizens and to interests in which at least 60 percent of the captal is owned by Filipinos. United States citizens, under a constitutional amendment and the Revised United States-Philippines Trade Agreement, have the same privileges as Filipinos until July 4, 1974.

A license is not required to prospect on public lands which are not reserved for other purposes, or on private lands. However, written permission of the owner and a deposit to cover compensation for any damages is necessary before prospecting on the latter.

Africa

Liberia

The laws of Liberia were revised in 1956. The basic mining laws of the Republic are found in Chapters V and VI, Title 24, of the Liberian Code of Laws of 1956. The right of mineral exploration or exploitation is granted to foreign nationals and companies after the required permit, license, or concession is obtained from the Government. With the exception of ordinary construction materials and salt, all minerals on private and public lands belong to the State.

The Bureau of Mines and Geology receives applications and grants nonexclusive rights to prospect with certain limitations. If the application is for exclusive exploration rights, the Mining Board must approve it, and if it is for prospecting in remote areas, the concurrence of the Secretary of Interior is required. Prospecting rights permit the sinking of pits for sampling, but do not permit commercial mining. No work is allowed on private land without the owner's permission.

A request for a license to explore goes first to the Bureau of Mines and Geology, and if exclusive rights are desired, the request must also be approved by the Mining Board. The applicant must have sought permission of the owner prior to applying for a license to explore on private land. If the owner refuses permission, the Government may issue the license and establish compensation to be paid or have the licensee post bond for possible damage that may occur during exploration. Either side has the right to seek a court settlement.

If a prospector has located a mineral deposit, he may claim as much as 2,000 acres. To file for a mining right, the claimant must erect posts on the claim corners, place a notice on the property, and also file the notice with the proper Government offices. Complete mineral information and a survey of the claim is required. A mining concession must be approved by various government officers, including the Secretary of State and the President.

Special concessions concerning iron ore and other minerals have been granted by the Government. There are four leading iron ore producers in Liberia operating under special agreements with the Government: (1) Liberia Mining Co., Ltd., (2) National Iron Ore Co., (3) German-Liberian Mining Co. (Bong Mining Co.), and (4) Liberian-American-Swedish Minerals Co. The Kitoma Mining and Trading Co., an affiliate of Hanna Mining Co. and Landberg Thalman and Co. of New York, has a special concession and approval to develop iron deposits at Kitoma, and the Liberian Iron and Steel Corp. was granted a special 70-year concession in 1967 to develop an additional deposit in the Wologisi Range.

Sierra Leone

Under the basic mining laws all minerals are

controlled by the State, but means for prospecting and mining by private interests are provided. The basic law, Minerals Ordinance of 1927 (Chapter 144, Minerals, Revised Laws, 1959), regulates prospecting and mining. Prospecting is lawful with either a prospecting right, obtained from the Chief Inspector of Mines, or an exclusive prospecting license which must be approved by the Minister in charge of mines. A mining right or a mining lease also may be obtained subject to certain qualifications. A mining right, normally issued for a period of 1 year, gives the holder exclusive rights to a specified area, and may be renewed for further 1-year terms, while a mining lease is for 5 to 99 years and carries an obligation to mine continuously. In the past the government has offered certain tax and tariff exemptions in efforts to attract private investors.

A new mining policy announced by the Prime Minister in Dec. 12, 1969, proclaimed the intention of the State to enter partnership agreements with each of the mining companies operating within its border. Under this policy the Government would ultimately purchase a majority ownership in all mining companies. Presently, only the British-owned Sierra Leone Development Co., Ltd., mines iron ore in Sierra Leone.

Republic of South Africa

Mineral laws of the Republic of South Africa are based on those of the former territories which were in force prior to the formation of the Union in 1910. The Republic has the power to enact mineral legislation, although mineral laws which were in force are largely still in effect in the respective provinces. Administration of the old laws and most of the other mineral legislation is the responsibility of the Central Government's Minister of Mines.

Alien residents have the same rights and privilges of land-holding or acquisition of minerals as do citizens, although racial segregation legislation complicates the situation. Under the South African mining law the owner of mineral rights on Crown or private land can mine base metals and minerals. The Government can lease mining rights for Crown lands, and under the Base Mineral Amendment Act of 1942, it can prevent base minerals from being locked on private lands.

Oceania

Australia

Mining legislation in Australia is the prerogative of the various States. For all practical purposes mineral rights are vested in the Crown, as represented by the appropriate State Government. Subsequent to 1888, freehold land titles reserved all minerals to the Crown, unless specifically granted for development purposes.

Although the individual State controls mineral rights, legislation throughout the Commonwealth Government affecting minerals is similar.

For the purposes of all State Mining Acts, land falls broadly into two main classes—Crown and private lands. The holder of a Miner's Right may take possession of and exclusively occupy any Crown land within the State of issue for the purpose of mining thereon. Entry to private land requires special permission, application being made to the State mining warden of the particular area. In Western Australia, where most of the iron deposits have been found, the mining laws are codified in the Mining Act of 1904-52, and regulation is by the Secretary of Mines. Permits to explore can be granted to persons holding a Miner's Right but may not exceed 1,000 square miles, although the number of permits that may be held by one individual or company is not limited. The permits are valid for 2 years, are renewable at successive 1-year intervals, and grant exclusive rights for exploration over the permit area. A filing fee is charged for each permit.

Licenses to prospect may be obtained by a permit holder, and are limited to 200 acres, with no limitation on the number of licenses held. These are valid for 4 years, may be renewed twice for 1-year periods, and carry the right to conduct intensive prospecting activities, including drilling. A performance bond must be posted and an annual tax is levied depending on the surface area involved.

In Tasmania, mining legislation is compiled in the Mining Act of 1929. A right to prospect covers 50 acres, a mining lease of 80 acres, and the area granted under a mining right will vary depending on the mineral.

Special leases may be granted by an individual State depending on the circumstances, and usually carry more detailed requirements and conditions. For example, the Western Australian Government gave official approval to the Mt. Newman iron mining venture by enacting the Iron Ore (Mt. Newman) Agreement Act, 1964. This involved three lease areas covering 300 square miles, and was similar to two previous Acts covering the Mt. Goldsworthy and Hamersley projects. The mineral lease was granted for 21 years with rights to extension. Royalty rates are based on a percentage of revenue from the ore. The act sets out certain

company obligations with respect to the development of secondary processing facilities and the construction of a steel mill. Contract agreements for future sales of ore also must meet with Government approval.

Income tax since July 1942 is levied only by the Commonwealth Government, with the States being reimbursed by grants out of the revenues received. Companies are taxed upon their taxable incomes, which comprise profits derived in Australia. There are no legal restrictions requiring local participation in equity capital or management in Australia by foreign interests. A convention is in operation between Australia and the United States for the purpose of avoiding double taxation, as well as preventing evasion of fiscal responsibility with respect to taxes on income by companies or individuals operating in both countries.

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CHAPTER 10.—STRATEGIC FACTORS

Iron ore is a vital element in the economy of the United State during peace and war. Since the national stockpile was established by the 79th Congress through Public Law 520 (60 Stat. 596) enacted July 23, 1946, the advisability of stockpiling iron ore or pig iron has been studied about every 5 years. Stockpiling has been deemed impractical in view of the size of the domestic reserve, the quantities that would be involved, and the extent of the normal industrial inventory. Transportation of domestically produced iron ore from the mines to consuming centers has been indicated as the key factor to be satisfied to assure iron and steel supply in the event of an extended period of emergency. Inasmuch as the transportation systems that handle iron ores are integral parts of the nation's overall transportation network, plans to move iron ore during an emergency have been coordinated with plans to move all bulk materials. However, special studies of alternate routes for moving iron ore have been made, and the last two iron ore mobilization studies have included a review of lake- and ocean-port facilities.

SELF-SUFFICIENCY

The United States has not been self-sufficient in iron ore since World War II. Imports of iron ore have increased from 7.4 million long tons in 1949 to 40.8 million tons in 1969. Compared with domestic iron ore consumption, imports in those years were 8 percent and 29 percent, respectively. Iron ore exports from the United States for the same years were 2.4 millions tons or 3 percent of domestic production, and 5.1 million tons or 6 percent.

The marked increase in imports was the direct result of cost-quality competition from high-grade ores. Iron ore imports are believed to have reached proportional equilibrium with domestic consumption and domestically produced pelletized ore. Therefore, on the basis of the present state of technology and the current economics of the United States and competing countries, the United States is judged two-thirds self-sufficient in iron ore.

PRICE AND PRIORITY CONTROLS

During World War II, Iron ore prices were controlled by the Government, and iron mines were given priority to obtain essential machinery and supplies. Direct Government control over the iron ore industry during the Korean War was authorized but not used. Priority for the mining industry to obtain maintenance, repair, operating supplies, and capital addition was issued by the Government in August 1951 and revoked in July 1953. This priority applied to the iron ore mines and mills. Judging from these past Government actions and the strategic value of the domestic iron ore industry, iron ore mines and mills are assured preferential treatment in obtaining essential supplies in a National Emergency.

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