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IRON ORE EXPLORATION AND EXPLOITATION ON A LARGE SCALE

by

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SUMMARY

1. Iron mining on a large scale is illustrated by experience on the Mesabi range, which has been the principal source of iron ore in the United States for more than 60 years. The Mesabi range is a 400-square-mile area, approximately 110 miles long, and 2 to 10 miles wide, in which residual iron deposits were formed from taconite rock. Geologic investigation of the range has preceded and facilitated exploration. Taconite rock, which has been mined commercially only since 1955, is supplanting residual deposits of enriched ore as the major source of iron. The enriched residual ore has been mined principally in open pits by power shovels and rail haulage. Trucks and conveyor systems have supplemented and partially replaced rail haulage since 1936. Taconite is mined in open pits by power shovels with rail or truck haulage. Both the residual and taconite ores are beneficiated. Quality control is a significant part of operations.

2. Experience in exploiting the Mesabi range iron ores has shown that 5 to 10 years elapse between first interest in an iron resource and construction of a plant to exploit it on a large scale. Careful planning, flexibility in adopting new equipment and methods, a high-quality product, concern for employee well-being, and favorable Government policy are among the elements leading to successful exploitation of an iron ore deposit on a large scale.

1. INTRODUCTION

3. Exploration and exploitation of the Mesabi iron range in the State of Minnesota, which is part of the Lake Superior iron mining district of the United States, has been selected to illustrate large-scale iron mining practices. Many problems encountered in developing the iron deposits there are the same as those that can be expected in any large-scale iron mining operation. The methods used to solve the problems are universally applicable.

4. The Mesabi iron range, shown in figure 1, lies an average of 75 miles Northwest of the head of Lake Superior. It is approximately 110 miles long, its width ranges from 2 to 10 miles, and it covers a total area of about 400 square miles. The range commonly is divided into 3 areas of similar type ore deposits: (1) Eastern Mesabi, metamorphosed by a gabbro intrusive, source of magnetite ore, (2) Central Mesabi, oxidized iron formation, source of enriched direct shipping ore, and (3) Western Mesabi partly oxidized and leached, source of wash ores.

5. The range is at elevation of 1400 to 1900 feet above sea level. The climate is severe in winter and mild and pleasant in summer. Winter weather greatly influences iron ore mining and transportation. Soft and hard wood timber, heavy underbrush, and muskeg swamps cover most of the area. Pine timber on the range was cut before iron ore mining started.

6. Geologically, the Mesabi is in gently dipping sedimentary rocks of the Biwabik iron formation of the middle Precambrian age. This formation is made up of four principal members, upper slaty, upper cherty, lower slaty, and lower cherty. The cherty members consist largely of ferruginous chert in relatively thick beds. The slaty members are physically similar to slate and are in relatively thin beds. The Biwabik formation is similar to the hard metamorphosed quartz hematite magnetite deposits of the world that depending on locality are called taconite, jaspilite, or itabirite.

7. Iron ore was discovered on the Mesabi range at Mountain Iron in 1890. It was a relatively primitive area at the time, although lumbering camps were established and two railroads crossed it. In the beginning crude ore was mined from open pits by horse-drawn scrapers and wagons, and the first shipment of ore was made from the range in 1892. In 1893 a steam-powered shovel was brought to the mines overland 12 miles through heavy timber from the town of Mesaba on the railroad, and that same year rail haulage replaced the wagons in the pits. Within 2 years three railroads served the range, and it had become the principal source of iron ore for the United States steel industry.

8. The type of iron ore used by United States industry has changed greatly since the Mesabi was discovered. Direct shipping ore has been largely replaced by beneficiated ore, which is currently being replaced by taconite concentrate pellets, but the Mesabi range has continued to be the principal source. The range has produced more than 2.4 billion tons of iron ore. Annual production figures are given in table 1 of the appendix.

II. EXPLORATION

9. Geology

a. The general geology of the Mesabi area in 1891 was described by N.H. and H.V. Winchell (38).[1/] Charles Leith (18) mapped the range in the early 1900's. He concluded that the ore deposits were formed solely by Precambrian surface waters leaching the silica and other impurities, leaving an enriched residue, and determined that the deposits were largely but not invariably in the rock synclines. Leith's work has been the basis for exploration of essentially all of the enriched ore bodies.

b. The low-grade magnetite deposits at the eastern end of the Mesabi range were described by Broderick (1) and Grout (11) in 1919, and Gruner (12) extended detailed study of the Biwabik formation to the western Mesabi area in 1924.

c. In 1954, after mining had exposed enough of the rocks on the range, D.A. White (36) refined the stratigraphy and structure. His work has been more theoretical than practical to date, but his interpretation and the additional geological information he obtained undoubtedly will have both practical and theoretical value in the future. In 1962, Gundersen and Schwartz (13) published a detailed study of the stratigraphy and mineralogy of the Biwabik formation in the eastern part of the range, in which they identified 22 submembers. Their work will have great practical value in future exploration of taconite because they established clear correlation between lithologic types and the concentrating characteristics of the rocks.

d. Engineers of the Bureau of Mines, United States Department of the Interior, (9, 26, 34) have systematically sampled pit banks and waste piles over the length of the range. The samples have been analyzed chemically

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1/ Numbers in parentheses refer to items in the bibliography at the end of this report.

and subjected to screen analysis, magnetic and heavy medium separation, and petrographic studies. They have also classified them according to their response to reduction roasting and magnetic separation. Thus, knowledge of the geology, stratigraphy, structure, mineralogy, and amenability to beneficiation has preceded and continues to precede mine development.

10. Drilling and Sampling

a. In the early days, the iron deposits of the Mesabi were explored by test pits dug with pick and shovel. This practice was soon changed to exploration using churn drills and diamond drills as the easily accessible deposits marked by outcrops were found and as the depths of overburden increased. The need to find and obtain titles to ore deposits quickly was also instrumental in changing the exploration practice. Soft ore at shallow-to-moderate depth was explored principally with churn drills; harder ore at greater depths was explored with diamond drills.

b. Mesabi engineers have depended on the geologic features and magnetic anomalies to guide exploration in finding and outlining the ore bodes. On the other hand, in exploration to determine the reserves and delineate the deposits for mining, engineers have been inclined to locate drill holes systematically. It has been usual practice to space holes 200 to 300 feet apart, the 200 foot spacing being almost standard for the average size ore body. When the first holes indicated unexpected geologic features or lack of continuity, the drill pattern was modified to accommodate the conditions encountered.

c. Engineers have utilized magnetic anomalies and topographic and geologic maps to fix the drill patterns for exploring taconite deposits. Hole spacing has not been standardized.

III. EXPLOITATION

11. General

a. Iron ore has been mined both underground and in open pits on the Mesabi range, but underground operations are excluded from this discussion because they have become relatively insignificant. Open-pit mining on the range naturally falls into two categories: (1) Enriched ore mining, and (2) taconite mining. Only the broad aspects of each category will be covered. The reader is referred to the references for the details of operations.

b. The term "enriched ore" as used here includes all ores mined that have a higher grade than the original taconite rock. Enriched ore mining practices have evolved to their present state during 60 years of constantly improving techniques. Changes have been gradual and modified by the need to amortize excavating equipment and the reluctance of the engineers to adopt new methods until they were proved. Therefore, the technical literature and even mining engineering textbooks contain complete, detailed, and in most instances, up-to-date accounts of methods used. Moreover, the methods developed for mining the direct shipping and high-grade, enriched ores of the Mesabi have been adopted for mining other elements besides iron, and their use in iron mines has spread throughout the world.

c. Methods of mining taconite have also been improved since beginning of operations in 1955, but in contrast to the enriched ore mining, the overall pattern of mining has been essentially unchanged.

d. Taconite is mined in Minnesota by the Erie Mining Company at the Erie Commercial Pit, and by the Reserve Mining Company at the Peter Mitchell Mine. Both mines are in the metamorphosed area in the eastern part of the Mesabi range where the principal iron mineral is magnetite. Erie crude ore is concentrated and agglomerated in the Hoyt Lakes plant at the mine. Peter Mitchell crude ore is crushed to minus 3½ inches at the mine and concentrated and agglomerated 42 miles from the mine, at the E.W. Davis plant at Silver Bay on the north shore of Lake Superior. These two mines and accompanying beneficiation plants have an approximate annual capacity of 13,500,000 long tons of pellets which is currently being increased to 16,500,000 long tons by expansion of the E.W. Davis plant.

e. Commercial exploitation of the taconite ores is a recent accomplishment, but it took almost 40 years of research, 15 years of pilot plant trial-and-error testing, and drastic revision of State Government tax assessment policy to get the job done.

f. D.C. Jackling, who had earlier gained renown as a pioneer in large-scale mining of porphyry copper deposits, and associates became interested in the taconite deposits in 1912, and conducted a drilling campaign and a metallurgical investigation of the ores in 1915 and 1916.

They formed the Mesabi Iron Company to exploit the taconites and built a mill and sintering plant for this purpose at Duluth in 1916. This unit operated until it became unprofitable in 1924.

g. Taconite mining on the Mesabi range actually did not become economically feasible until 1941 when the State of Minnesota passed a law limiting the amount of ad valorem tax that could be assessed against taconite deposits and mining facilities.

h. Anticipating passage of this law, the Reserve Mining Company was organized to exploit the Peter Mitchell mine in 1939, and obtained a lease from the Mesabi Iron Company that same year. The Erie deposit was delineated in 1938 and 1939 by an extensive exploration campaign, and the Erie Mining Company was formed to exploit the property in 1940.

i. When these companies were formed, the methods for crushing, grinding and concentrating taconite and agglomerating the fine concentrate were well understood. Among the many mining and processing techniques now used in exploiting taconite, only a satisfactory method for sinking blast holes in the hard rock had not yet been developed past the laboratory stage. Nevertheless, the two companies spent years in pilot plant research before deciding on the final design of the commercial concentration plants, and the plants did not produce until more than 15 years after the operating companies came into existence.

12. Enriched Ores (15, 16, 30, 31, 40)

a. Plan and Layout

i. Essentially all the large mines of the Mesabi range were developed for rail haulage. In every instance, the shape of the deposit was delineated by development drill holes. Track layouts were predetermined to facilitate stripping and mining with spiral pattern preferred. Switchbacks were used as needed to obtain complete extraction. Track grades were held to 1½ percent loaded, 5 percent empty. Most operations were planned so that stripping and mining could proceed simultaneously. Pit bank slopes ranged from 1:1 to 2½:1, depending on the physical characteristics of the overburden and of the ore.

ii. The maximum economical stripping ratio increased from 1 to 1 in the 1900's to as much as 2 to 1 in recent years as more efficient earth-moving equipment became available. Mining and stripping benches ranged in height from 25 to 35 feet. A 20-foot berm was planned between the ore and overburden, and also, in the overburden every 75 feet of depth.

iii. Mining plans in all the large pits have been modified progressively and have kept pace with improvements in equipment that provided greater flexibility and cleaner mining. Haulage layouts in many instances were completely changed with inception of off highway trucks, conveyors, and skip systems and as the pits were depleted. Truck haulage roads were planned on a grade of 5 to 10 percent for loaded trucks and as much as 20 percent for empties.

b. Stripping

i. Stripping on the Mesabi range has been mostly a dirt-moving operation and is usually conducted during the winter months. Material has been loaded with power shovels, first steampower, then electric, and within the last 20 years diesel-electric power shovels have come into common use. Dipper sizes have ranged from the first half cubic yard, to 8 and 10 cubic yards. Some stripping shovels have been equipped with interchangeable booms to form draglines. Dragline buckets have ranged in size from 4 to 30 cubic yards.

ii. Haulage equipment began with a 6-ton dinkey steam locomotive on a 36-inch gage track. Present practice is to use the largest standard gage switch engines available on heavy rail with 30 cubic yard air dump cars. Since the 1930's there has been a trend to truck and conveyor belt haulage, but in that period most newly developing enriched ore mines on the Mesabi have been relatively small.

iii. Overburden has been blasted as necessary. Where possible the waste piles have been put in low areas and kept straight to facilitate moving the haulage track.

c. Mining

Loading equipment in mining has followed practically the same pattern as that in stripping. Four cubic yard dipper, power shovels have become the practical standard because they provide greater flexibility. Rail haulage has been supplanted by truck plus rail, truck plus conveyor, and truck plus skip to avoid excessive grades and track length in the deeper mines. Common practice is to mine in 25 to 35 foot benches. The ore is drilled with 6- to 9-inch churn drills, rotary, or down-the-hole drills.

d. Quality Control (25)

Quality control of Mesabi ores begins at the mine. Blasthole samples are used for quality control at the face. In the first mining, only the high-grade ore was taken. This soon gave way to the practice of mixing high-grade ores with low-grade to obtain the maximum quantity that would meet market specifications, a practice which has continued to the present but is fast disappearing with demand for higher and higher grade materials. Only the high grade meets most specifications. Ore quality for market is controlled within the transportation system as explained later in paragraph 12. e. iiii.

i. Beneficiation

Ore beneficiation began on the Mesabi about 1907 when washing plants were installed to exploit the ore bodies in the western part of the range and since then beneficiation has become increasingly significant, and currently more than 60 percent of the enriched ore produced on the range is beneficiated. Jigs and heavy medium separators using ferrosilicon or magnetite are common. A flotation unit was installed in 1957 to treat heavy media tailings. Plant sites have been selected to facilitate tailings disposal in nearby low areas.

e. Transportation (21, 22, 23, 37)

i. Practically all Mesabi ore moves by rail from the range to loading docks at the head of Lake Superior where it is transferred to ore carriers, then taken through the Great Lakes to market. The system is comparable to that of an iron mine within 100 miles of any ocean port, except that winter weather stops the operation for about 4 months each year and the ships must be small enough to pass through locks between the Lakes.

ii. Much of the transportation system was in existence when ore was discovered on the Mesabi in 1890. Two railroads crossed the range, one of which regularly transported iron ore from the Vermillion range to ore docks on Lake Superior at Two Harbors. A rail net was extended throughout the range by 1900, and new ore docks serving the range were built on Lake Superior at Duluth and Superior.

iii. The design of the ship loading docks has changed very little during the years. Ore is dumped directly from railroad cars into pockets 12-foot on center. Each pocket holds 5 carloads. From the pocket ore is loaded by gravity through chutes into ship hatches.

iiii. The transportation system by which Mesabi iron ores are delivered to market is a significant element in quality control and a classic example of sampling and grading techniques. (25) Briefly it consists of sampling 4 or 5 car-groups at the mine and reporting the results to a grading office, which assigns each group to a block which is built up to cargo size, or several blocks are combined to make a cargo. Sampled cars are reassembled at switching yards on order from the grading office and unloaded and mixed in ore pockets to make up the ship's cargo of the desired specification grade. By careful planning and mixing the ore from many mines, it is possible to market ore of guaranteed analysis even before it is mined.

f. Facilities

i. Fuel, Power and Water

Coal and oil are delivered to the Mesabi Range over the same system that delivers the iron ore to markets. Electric power has been available on the range from an independent, privately owned, power company which operates both steam and hydro-electric plants. Water to exploit the enriched ores has been easily obtained from many streams and lakes in the area.

ii. Housing

In the earlier history of the range, mining companies constructed houses in communities near the mine and rented them to their employees, but there has always been a large segment of privately owned, independent communities. The proportion of company-owned housing decreased markedly with the advent of the automobile, and for practical purposes, company-owned housing has not existed on the Mesabi range for the last 10 years.

13. <u>Taconite Ores</u> (5, 6, 8, 26, 29)

a. Plan and Layout

i. Planning a taconite mine on the Mesabi range differed very little from planning a mine in the enriched areas of the iron formation except that the scale of operation was much larger. The Erie mine was planned to produce more than 69,000 long tons of crude ore per day. The Peter Mitchell mine was planned eventually to produce more than 90,000 long tons per day.

ii. The ore bodies, each approximately 9 miles long and ½ mile wide, were delineated by drilling and sampling and carefully mapping the outcrops and topography. Pits were planned so that stripping of hard rock would not exceed 20 feet. Slopes in overburden and in the ore and haulage grades presented no problem as the greatest thickness of taconite to be mined will not exceed 175 feet. The Erie mine was laid out in 2 pits with the average haul to the crusher in the center at present of about 3 miles. The Peter Mitchell mine was laid out in a 2½-mile pit which will be elongated as required. Both mines were designed for rail haulage, but the first cut through of the Peter Mitchell was to be made with trucks hauling the ore.

iii. The original plan at the Peter Mitchell was to install rail haulage after the first cut was through the pit. However, a year of operating experience indicated that the advantages to be obtained from rail haulage would be more than offset by the difficulties of blasting the hard taconite rock in a narrow cut, and the haulage plan was changed to use truck tractor-trailer 45-long-ton capacity, side-dump units.

b. Stripping

Overburden is stripped from the taconite deposits with 2½, 5, 6, and 8-yard electric shovels. The material is transported to waste piles in off highway trucks, except that at the Erie mine all rock overburden is moved by rail. At both mines, the top of the taconite is cleaned with the smaller shovels working with tractor-mounted bulldozers. Overburden is drilled with rotary and down-the-hole drills. At the Erie operation to date, down-the-hole drilling has proved superior in the softer portion of the slaty layers; rotary drilling has proved superior in the harder portions.

c. Mining (7, 27, 32, 39)

i. The ore is loaded with 8-yard shovels equipped with 5 cubic yard dippers at the Peter Mitchell mine; the 8-yard shovels are equipped with 8-yard dippers at the Erie pits. Reserve Mining Company has purchased 11-yard shovels under its expansion program. Mining benches at both operations are 30 to 35 feet to as much as a maximum of 45 feet high with the average being 35. Ore is hauled on standard gage track in cars of 80-ton capacity at the Erie mine and in the aforementioned tractor-trailers at the Peter Mitchell mine. Under the expansion program 85-ton capacity trailers will be used.

ii. Oxygen and fuel oil jet piercing and heavy rotary drills are used to put down all taconite blast holes as ordinary drilling methods proved inefficient and impractical in the hard rock. Engineers at Peter Mitchell mine have found that a 20- by 20-foot pattern gives the best results. At the Erie mine, an 18- by 18-foot pattern is used in box cuts and a 19- by 28-staggered pattern is used in open faces. Holes are drilled 3 to 4 feet below the pit floor. A TNT slurry is used for blasting in wet holes, and ammonium nitrate and fuel oil is used in dry holes. Although blasting efficiency has been increased almost unbelievably since the start of operations, the engineers at both mines are still experimenting and striving for better fragmentation.

d. Quality Control

Quality control in mining taconite begins at the mine, the same as in mining the enriched ores. The first control is exercised through the results of the exploration drilling in which the analyses of mineral characteristics and structure of each area are carefully noted. This information supplemented with that obtained from the mining face, is used to plan operations so that a feed of uniform grade, mineralogy, and hardness will be delivered to the crusher. At the Erie mine, a Ramsey coil measures the magnetic iron content of each train load of ore after it has passed through the primary crusher. A large variation from the expected grade is investigated immediately, and the mining operation is adjusted accordingly. Grading the crude ore to obtain a uniform plant feed facilitates beneficiation and results in a better quality product.

i. Beneficiation (10, 17, 19, 35)

Concentration of magnetic taconite is a simple thing theoretically, but a complex process practically. The ore passes through a coarse crushing plant, fine crushing plant, ball-and-rod fine grinding mills, magnetic cobbers, magnetic rougher separators, magnetic cleaners, and magnetic finishers. At Hoyt Lakes, the concentrate is further upgraded in a thickener equipped with water siphons to remove the finished product, which reduces the silica content of the concentrate by 0.7 percent. Erie concentrate averages approximately 65 percent iron and 7.8 percent silica. Reserve concentrate averages approximately 64½ percent iron and 9.2 percent silica.

ii. d. Pelletizing

The fine concentrate is pelletized (a new element in iron ore processing that stems from exploitation of the taconite deposits) (14) at both plants. At the E.W. Davis works, the concentrate is mixed with bentonite and anthracite coal fines, formed in a balling drum, and then indurated with heat in a down draft horizontal travelling grate furnace. (6) At the Hoyt Lakes plant, the concentrate is mixed with bentonite, formed in a balling drum, and then indurated in a shaft furnace. (24) The finished product is round, ½ to 3/8 inch in diameter, contains 63 to 65 percent iron, and is uniformally hard and durable.

(e). Tailings Disposal. - Tailings from the E.W. Davis plant flow in launders to nearby Lake Superior into a large natural trough that is 1,000 feet deep. Tailings from the Hoyt Lakes plant are pumped in a slurry, 35 to 40 percent solids, to a specially constructed tailings area which eventually will be 1½ by 2½ miles in size and several hundred feet high.

e. Transportation (33, 6, 8, 26)

i. New railroads were constructed to serve both Mesabi taconite operations. Crude ore is hauled approximately 45 miles from the primary crushing plant at Babbitt to the E.W. Davis works at Silver Bay by trains of up to 110, 85-ton capacity cars. The ore, after first being crushed to a maximum of 3½ inches, is loaded into the cars from storage bins. It is unloaded at Silver Bay with a rotary car dumper. Finished pellets are transported 72 miles from the Hoyt Lakes plant by 120 car, 85-ton capacity ore trains to the dock and shipping facilities at Taconite Harbor. Each car is equipped with a bottom dump mechanism, which allows it to be dumped automaticlly while the train is in motion.

ii. Ship docking facilities at Taconite Harbor have a total length of 2,634 feet, and at Silver Bay, 2,500 feet. At both, ships are loaded with conveyor belts. At Taconite harbor, the dock contains 25 pellet storage bins, 48 feet on center, each of which is serviced by a conveyor 42 inches wide with a shuttle length of 91 feet and a maximum reach beyond the dock base of 44 feet. Inasmuch as ship hatches are 24 feet on center, the ship has to make only one move at the Taconite Harbor dock to be completely loaded. The dock has a total storage capacity of 110,000 tons.

iii. The Silver Bay dock has five 6,000 tons capacity storage bins, served by two 60-inch belt conveyors equipped with retractable shuttles and boom which reach a maximum of 40 feet from the dock edge. The conveyors move parallel to the dock face and can draw pellets from any of the 5 storage bins. There is a paved area behind the dock with storage capacity of 1,700,000 tons of pellets. The area is served by a 465-foot travelling ore bridge equipped with a 202-foot cantilever section to cover a total of 667 feet.

f. Facilities

i. Fuel

Coal is delivered to Taconite Harbor and Silver Bay over the Great Lakes system. It is stored at dock side and used in adjacent power plants or transported to the mines as needed.

ii. Power

Power for the taconite operations is provided by coal fired steam driven turbines. The plant at Taconite Harbor, which supplies power to the entire Erie operation has a capacity of 150,000 kilowatts. The plant at Silver Bay which supplies power to the entire Reserve operation had a capacity of 40,000 kilowatts with an availability of 55,000 kilowatts, which currently is being expanded to provide a total capacity of 120,000 kilowatts. Both distribution systems are tied to the transmission lines of the independent, privately owned power company serving the area.

iii. Water

The Hoyt Lakes concentrator uses as much as 120,000 gallons of water per minute, about 95 percent of which is reclaimed. The water is obtained from a natural lake, and a natural lake reservoir controlled by the 30 feet high earth filled dam. The E.W. Davis concentrator uses about 10,000 gallons of water to process each ton of concentrate; at its capacity of 3,500,000 tons a year, it requires approximately 100,000 gallons of water per minute, all of which is drawn directly from Lake Superior. Inasmuch as the Davis plant tailings go into the Lake, essentially all water used at the plant is reclaimed.

iiii. Housing

Three completely new towns were built in virgin territory to serve the taconite operations: the town of Hoyt Lakes for the Erie Company plant, the town of Babbitt for the Reserve Company mine, and the town of Silver Bay for the Reserve Company plant. All three communities were planned and constructed to provide higher than average standards of living. The mining companies sponsored essential commercial, educational, religious, and recreational community facilities, and arranged special financing to encourage employee homeownership. The towns are self-governing within the framework of county, state, and Federal Government laws. The companies have divested themselves of all but the essential facilities. The homes have been sold to the residents and the public facilities turned over to the local governing bodies.

IV. DISCUSSION

14. Iron ore mining on the scale described is a tremendous undertaking that requires great skill in management; the services of highly competent mining, metallurgical, civil, mechanical, and electrical engineers, and long-term investment of hundreds of millions of dollars. It is also a highly

competitive business in which mining concerns in all parts of the world are engaged. Before embarking on such an enterprise, iron ore resources, capital and operating costs, and markets should be investigated carefully and completely.

15. The two taconite operations described have required long-term investment of more than $1 billion. Such developments on the Mesabi range would have been out of the question without access to low-cost capital, reserves assuring a long life, competent personnel to provide low operating cost, and proximity of a large and expanding market in a resilient economy.

16. Experience on the Mesabi range shows that time is the primary requisite for iron ore exploitation on a large scale, after resources and markets have been investigated and found to be suitable. Time is required to map and plan the operation, to construct the necessary plant and auxiliary facilities, and to operate and amortize any substantial investment. It follows that large-scale development of an iron deposit should be undertaken only in a stable environment, one in which there is a large degree of confidence that neither monetary nor political conditions will change sufficiently to make the operation unprofitable within the necessary long period of exploitation.

17. The large-scale iron mining operations of the Mesabi range from the very beginning to the present have had the following elements in common that undoubtedly account for much of their success: (1) The mines were carefully planned, (2) the plans were flexible and changed as new equipment and methods developed, (3) a premium-grade ore was produced to meet the demands of the market, and (4) better-than-average housing and facilities were provided for employees. It is also noteworthy that the State Government's tax policy was changed, contributing to the success of the taconite operations when it was proved that the taconite could not be mined profitably under existing policy.

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VI. APPENDIX

Table 1

Usable Iron Ore Production on the [illegible] Range, 1892-1963[a]

(Thousand long tons)

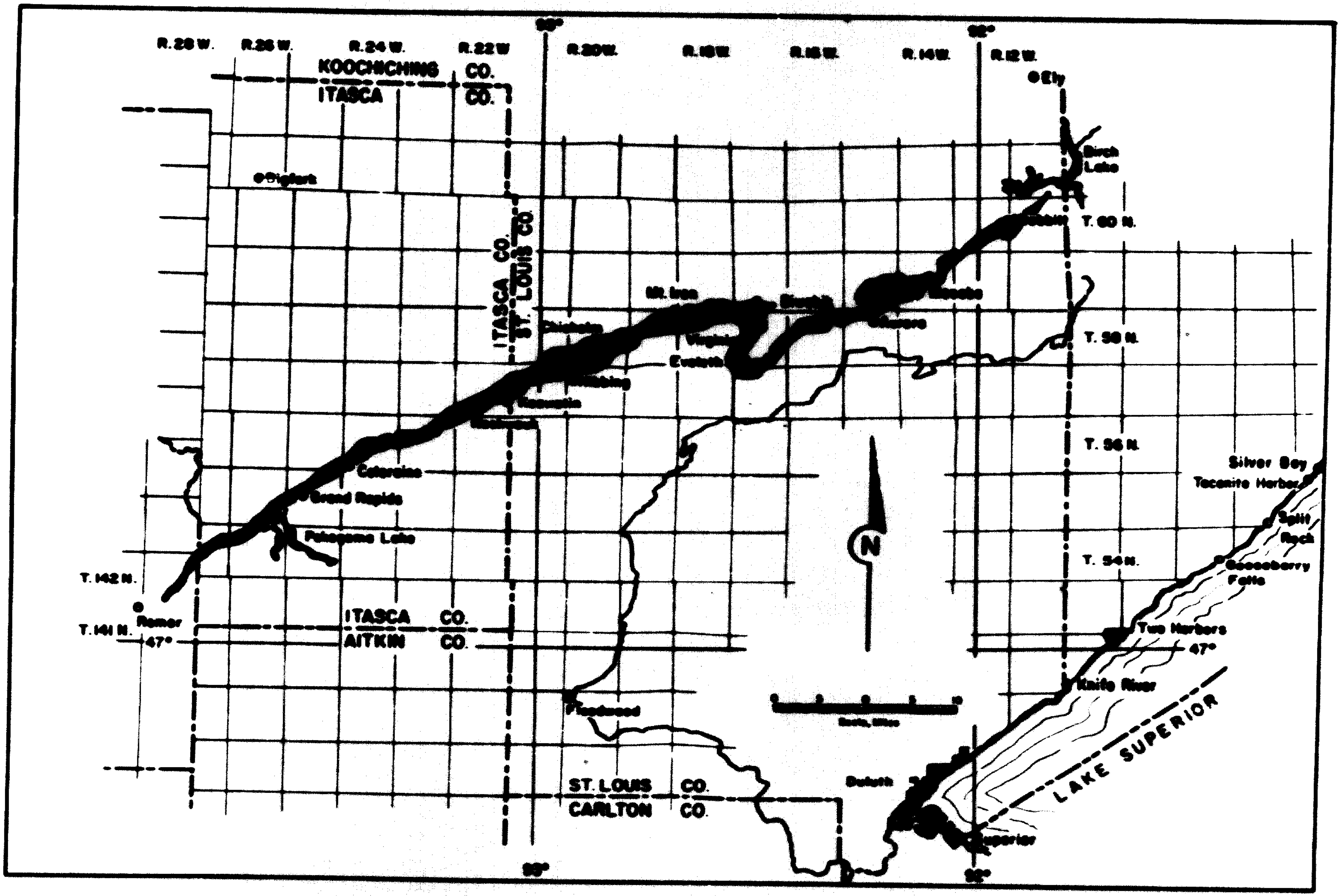
Year	Tons	Year	Tons
1892	29	1928	34,856
1893	684	1929	42,371
1894	1,913	1930	31,300
1895	2,839	1931	15,599
1896	3,083	1932	4,255
1897	4,220	1933	11,367
1898	4,839	1934	14,415
1899	6,517	1935	18,324
1900	8,158	1936	30,205
1901	9,304	1937	46,271
1902	13,080	1938	13,257
1903	13,453	1939	29,522
1904	11,672	1940	45,483
1905	20,157	1941	59,688
1906	23,565	1942	70,288
1907	27,245	1943	65,335
1908	17,725	1944	61,994
1909	27,878	1945	58,355
1910	30,576	1946	46,679
1911	23,127	1947	58,772
1912	32,605	1948	64,072
1913	36,379	1949	52,551
1914	19,868	1950	60,838
1915	30,802	1951	73,575
1916	41,325	1952	59,371
1917	41,127	1953	75,324
1918	39,056	1954	45,725
1919	33,263	1955	64,860
1920	36,642	1956	59,346
1921	15,380	1957	65,886
1922	25,705	1958	40,860
1923	41,809	1959	34,556
1924	29,819	1960	54,442
1925	34,851	1961	41,199
1926	37,998	1962	43,041
1927	32,856	1963	40,000 (estimated)

Total 1892-1963 2,[illegible]15,[illegible]81,000 long tons

[a] Usable iron ore is the [illegible] shipped to the consumer; it may be crude ore, [illegible] concentrate, [illegible] concentrate.

F I G U R E S

Figure 1. Location of the Mesabi Range, Minnesota



Map of the Mesabi Range, Minnesota

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Figure 2. View of Hull Rust open pit mine showing typical mining benches, electric power shovels, churn drills, and loading tracks with ore train. Courtesy of Oliver Iron Mining Division, U. S. Steel Corp.

Figure 3. View of Sherman Mine, electric power shovel loading ore train. The Sherman mine produced more than six million tons of ore in 1955. Courtesy of U. S. Steel Corp.

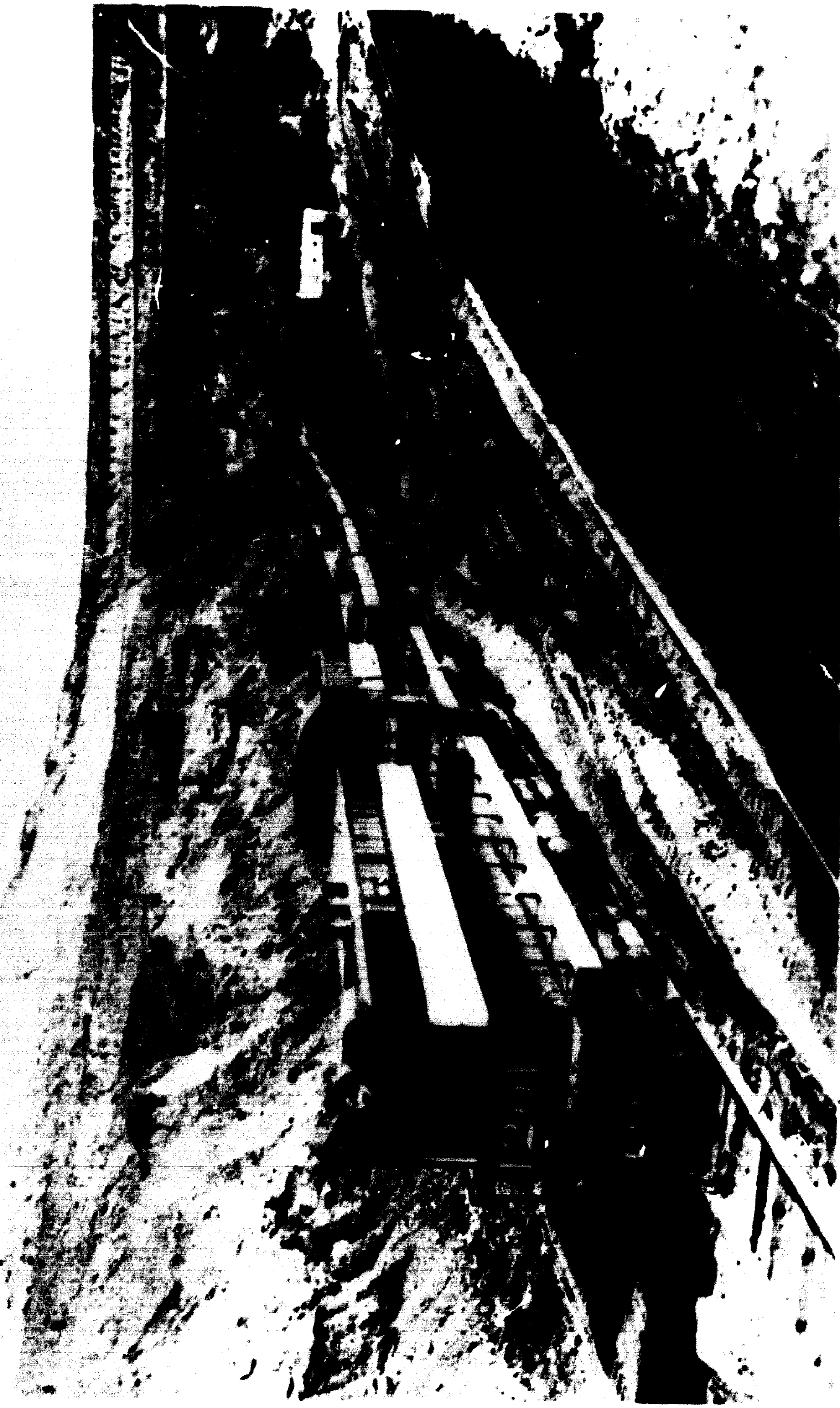

Figure 4. View of Pierce Group of Mines, showing stripping benches, track layout, and mine shops.
Courtesy of M. A. Hanna Company

Figure 5. View of South Agnew Mine showing churn drill, electric-power shovel, ore trucks, and haulage roads.
Courtesy of M. A. Hanna Company

Figure 6. View of Plummer Mine showing electric-power shovel loading ore trucks and motor road grader. Courtesy of U. S. Steel Corp.

Figure 7. View of Patrick, Patrick C, and Patrick Annex Mine showing mines laid out for truck haulage.
Courtesy of M. A. Hanna Co.

Figure 3. Aerial view of Patrick group of mines showing truck-conveyor transfer point, washing plant, waste piles, and tailings ponds. Courtesy of M. A. Hanna Co.

Figure 9. Aerial view of Mesabi Chief, Gordon, and Bray mines showing pit layouts, truck haulage roads, waste piles, and truck-conveyor transfer point. Courtesy of M. A. Hanna Co.

Figure 10. View of Portsmouth group of mines with concentrating and sintering plant in the background. Note: drag line loading ore. Courtesy of M. A. Hanna Co.

Figure 11. Aerial view of Tioga No. 2 showing first stages of mining after installations of underground conveyor system. Courtesy of Pickands Mather and Co.

Figure 12. Aerial view of Tioga No. 2 showing heavy media concentrating plant, ore storage piles, and railroad car loading bins. Ore is delivered from the mine by the covered conveyor on the right. Courtesy of Pickands Mather and Co.

Figure 13. Aerial view of South Agnew mine showing truck skip haulage. Courtesy of M. A. Hanna Company

Figure 14. View of iron ore docks, Great Lakes iron ore vessels, and iron ore railroad cars. Courtesy of Great Northern Railway Co.

Figure 15. View of Peter Mitchell taconite mine showing electric-power shovel loading 85-ton-capacity, side-dump truck-trailers. Courtesy of Reserve Mining Co.

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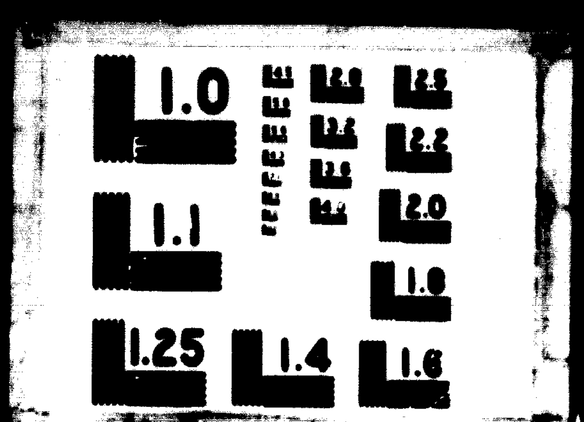
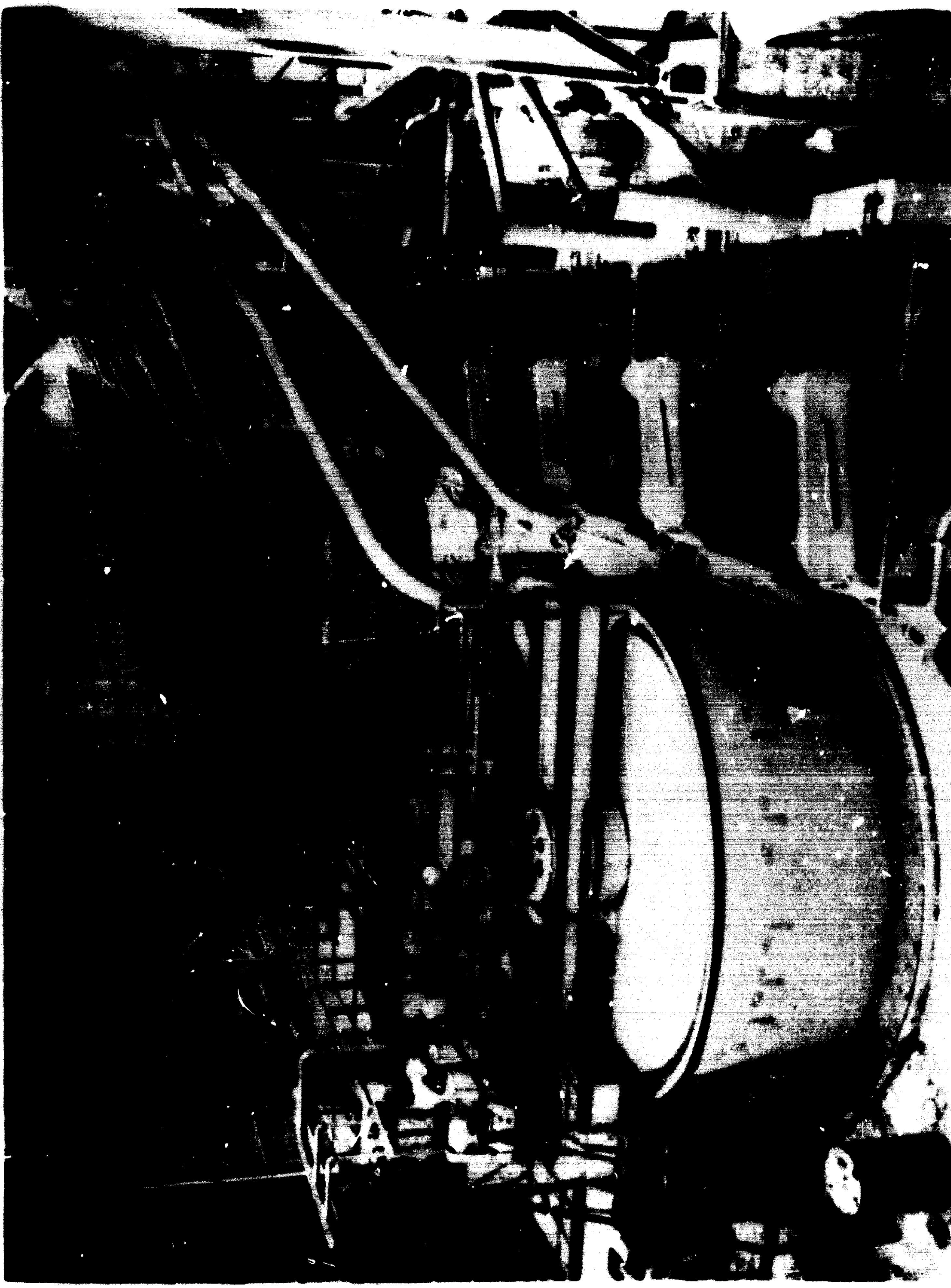


Figure 16. Aerial view of Erie Mining Company Hoyt Lakes concentrating and agglomerating plant. Courtesy of Pickands Mather Co.

Figure 17. Aerial view of the E. W. Davis concentrating and agglomerating plant, showing ore loading dock and storage facilities. Courtesy of Reserve Mining Co.

Figure 18. View of magnetic and hydroseparators at E. W. Davis concentrating plant. Courtesy of Reserve Mining Co.



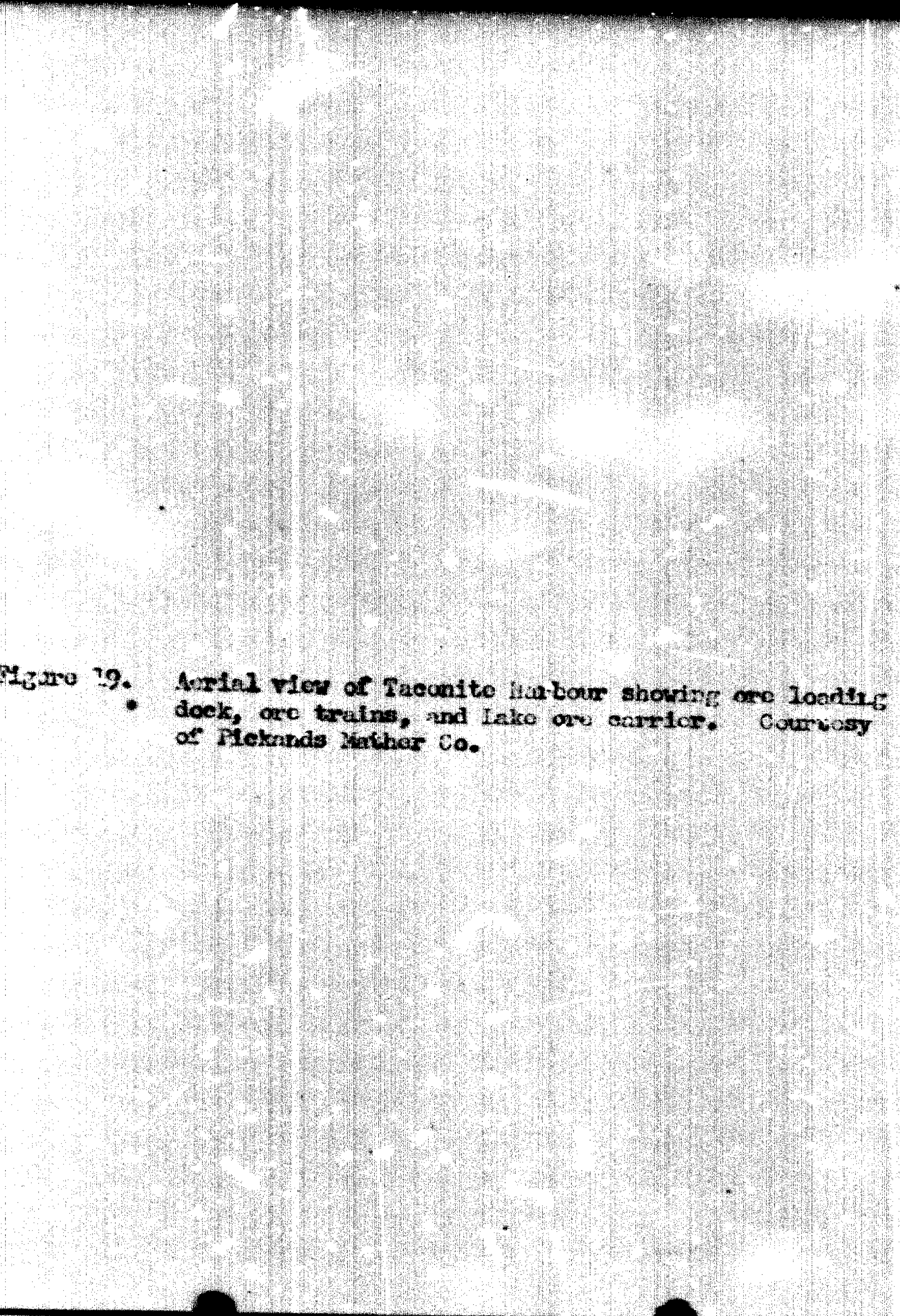
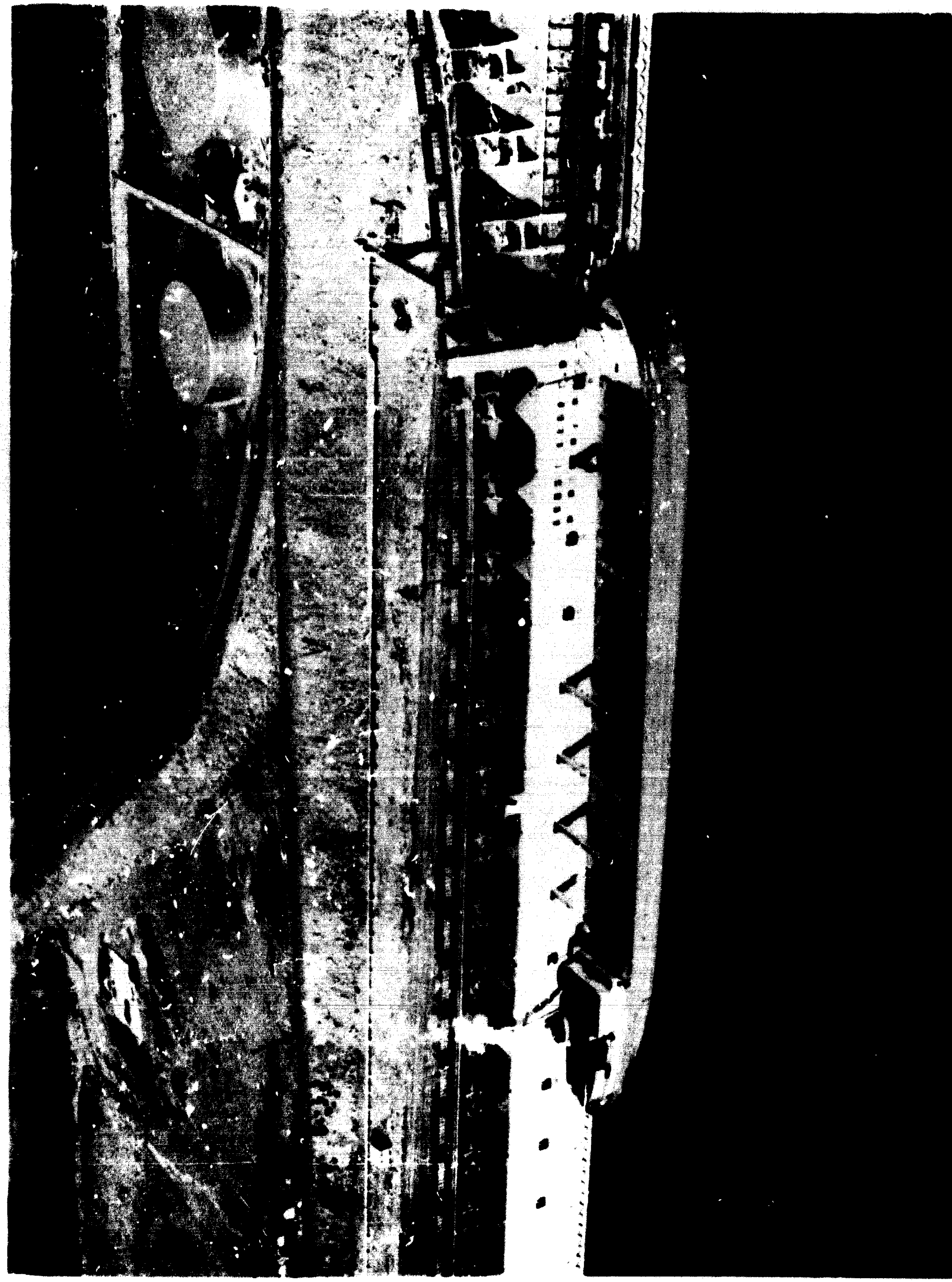


Figure 19. Aerial view of Taconite Harbour showing ore loading dock, ore trains, and Lake ore carrier. Courtesy of Pickands Mather Co.



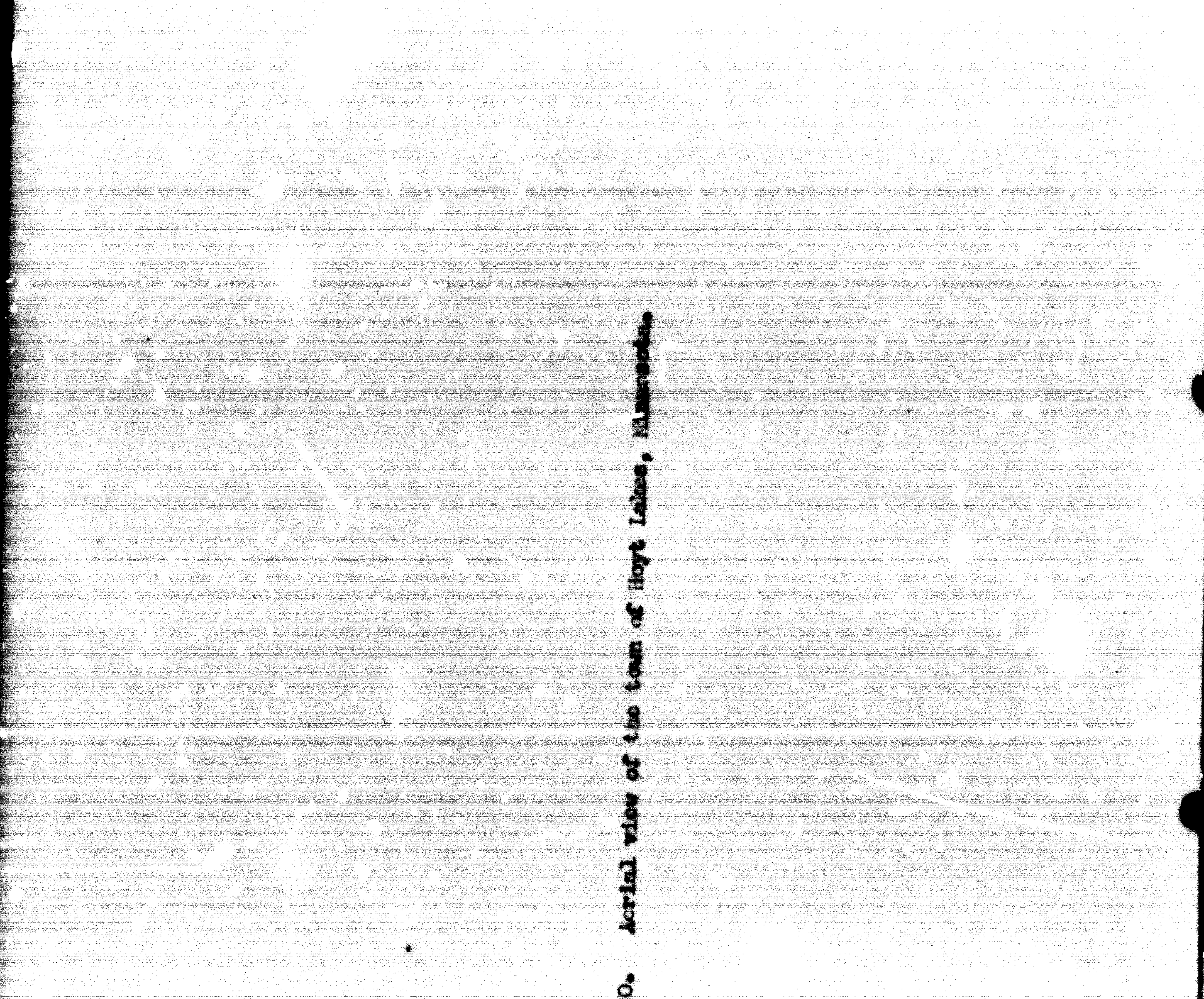


Figure 20. Aerial view of the town of Hoyt Lakes, Minnesota.

Figure 21. Aerial view of Virginia, Minnesota. The municipal water and light plant is in the left foreground; the Missabe Mountain Mine, part of the Rouchleau group of mines operated by the Oliver Iron Mining Division of U. S. Steel Corp. is in the background. Courtesy of Grand Rapids Herald-Review.

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