

Staying Alive: The Introduction of Slushing in Michigan's Underground Iron Mines

By
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The “slusher,” or “tugger-scraper,” is a simple artifact sometimes found at mining museums. It often sits in the midst of physically more imposing artifacts: giant pumps, large hoists, shovel loaders. It often has only minimal identification. The Cornish Pump Museum in Iron Mountain, Michigan, for example, features the very impressive steam pump which once kept the Chapin iron mine dry. The assortment of other mining artifacts displayed includes a tugger-scraper, identified only by name, with a photograph showing one in use.

The Soudan Underground Mine State Park, near Soudan, Minnesota, does a bit better. It has a tugger and associated scraper displayed outside with other mining equipment; an adjacent sign, with a sketch, describes how miners once used the implement to drag ore for loading.

But no museum devoted to underground iron mining, so far as I know, describes the truly critical role this simple device played in keeping underground iron mines alive after World War I, when they simultaneously faced competition from open-pit mines, declining ore prices, rising wages, and serious labor shortages.

In 1892 the first shipment of iron ore from the Mesabi Range in Minnesota rolled down the rails to Duluth, on Lake Superior, for shipment to Cleveland. The vast size of the Mesabi deposits, their relatively shallow depth, and their horizontal orientation meant that these rich ores could be mined using low-cost, open-pit methods. Cheap Mesabi ore soon flooded the American market. The onset of a major depression in 1893 accelerated the fall of iron ore prices and placed the underground mines of Michigan's Upper Peninsula—the center of American iron ore production for well over a decade—in peril.¹

As ore prices spiraled downward, panic pervaded the Michigan ranges. Recalling the early 1890s, William Kelly, a Michigan mine superintendent, wrote in 1900:

Few who have not been through it can appreciate the agony of heart which seized us when in the fall of '93 and the opening months of '94 we realized what great reductions must be made in cost to insure a continuance of operations and were confronted with the appalling condition that at the same time [due to economic depression] the output must be reduced enormously.²

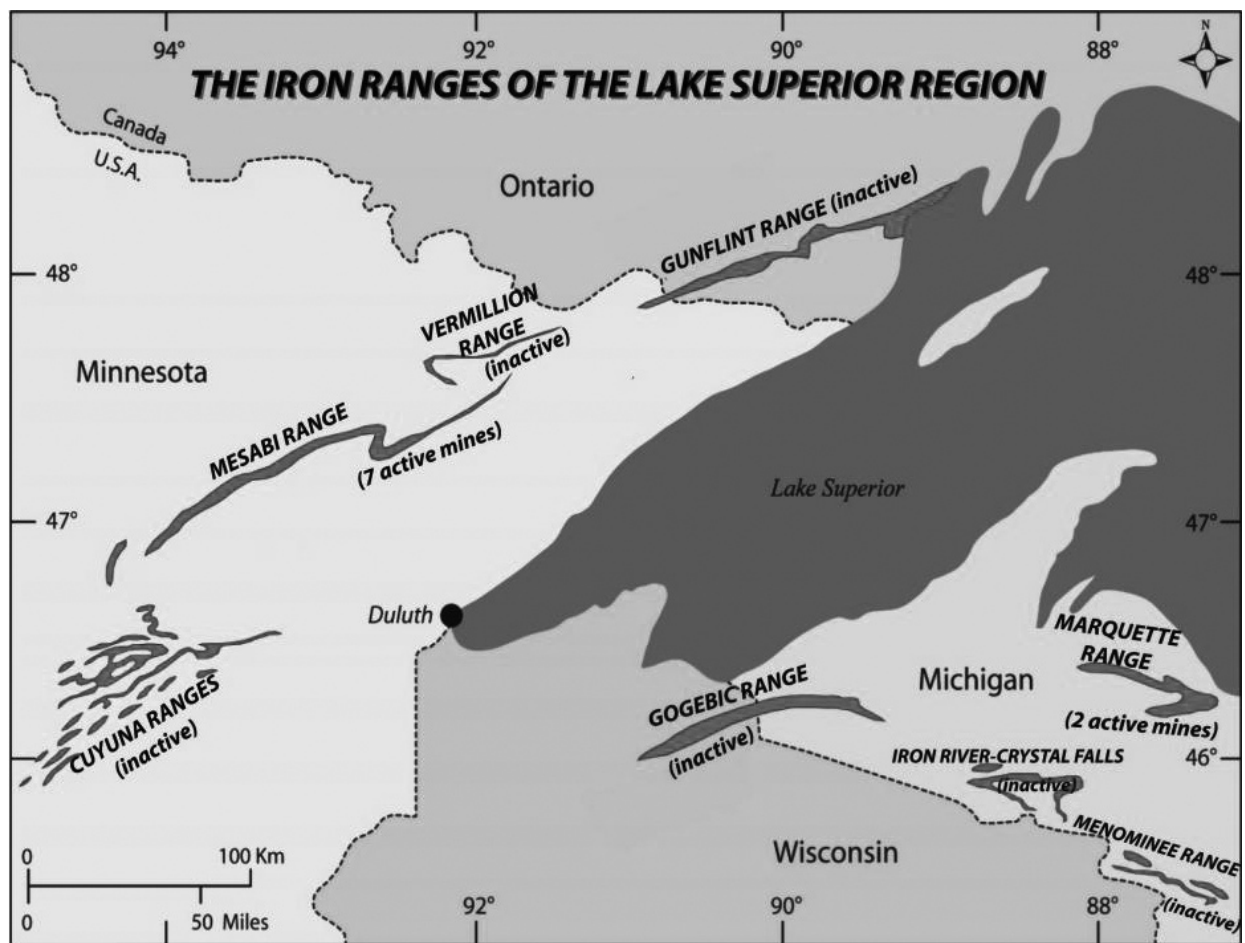
A lease holder of the Queen Mine on Michi-

gan's Marquette Range declared in 1896 that it was "impossible . . . to compete" with Mesabi ores.³ A leading Michigan iron range newspaper pleaded for "a perfect understanding" between labor and management to try to keep Michigan mines alive, and the *Iron Trade Review* noted that mining men feared the Mesabi "would swamp them."⁴

These fears had justification. By 1897, five short years after its first shipment, the Mesabi produced more ore than any other American iron range, and by 1907 it produced more ore than all other American iron mining ranges combined.⁵ How could underground ore operations survive?⁶ Mesabi open-pit mines often required removal of no more than fifty feet of easily penetrable overburden. Then steam shovels could load tons of ore in a single scoop directly into rail cars.



A Tugger-Scraper at Soudan Underground Mine State Park in Minnesota. The tugger unit is at left, with a modified hoe-type scraper at right. (Photograph by the author.)



The Iron Ranges of the Lake Superior Region. (William Cannon, USGS, "The Lake Superior Iron Ranges: Geology and Mining" <http://mn.water.usgs.gov/projects/tesnar/2011/Presentations/CannonIron%20ranges.pdf>)

In contrast, underground operations required extensive drilling and blasting to reach ore deposits often hundreds of feet underground through hard rock, supporting their shafts and tunnels with extensive timberwork. Then miners had to blasted the ore free, load it into mine cars by hand, a few dozen pounds at a time, and push the cars by hand to a shaft so that a hoist could raise the ore to the surface, where it was usually stock-piled before being loaded on railroad cars.

Underground iron mines, however, survived for over three quarters of a century after the Mesabi began shipping. In fact, until 1940 the proportion of iron ore mined underground in the United States remained close to 50 percent

and occasionally exceeded that mined by open pit.⁷ In Michigan, the locale of three major iron mining ranges—the Marquette, Menominee, and Gogebic—underground mines survived until the 1960s and one until 1979.

A detailed account of how Michigan's underground mines stayed alive would require an extensive treatise. The factors included a more favorable geographical location with respect to markets, lower shipping costs, blast furnaces' need to blend the fine-grained Mesabi ores with coarser and harder old-range ores, lower royalty costs, and Michigan's lower taxes. But equally important was the underground iron mining industry's very rapid adoption of labor-saving technological

innovations. One of the most critical was called slushing.

What is slushing? In brief, it is the use of power-drawn scrapers to move ore or waste rock underground. In a typical early slushing system, wire rope wound around a drum on a compressed-air-powered winch—usually called a tugger or hoist—and pulled a scraper that dragged ore along a mine floor to a point where the ore fell by gravity into a storage compartment or a mine car. At first, miners returned the scraper blade to the working face of the mine manually, but improvements soon mechanized that action through the use of a tail rope run through a sheave, or pulley, mounted near a working face, and connected to a second drum on the hoist engine. This enabled both pull and return to be powered. Alternate names for the slushing system included tugger-scraper, scraper-loader, scraper-hoist, and power scraper.⁸

Background: World War I and Labor Shortages

The emergence of the scraper-loader, or slusher, in Michigan's underground iron mines illustrates the old adage "Necessity is the mother of invention." The perceived necessities in this case were the need to reduce costs to remain competitive with open-pit mines and to counteract rapidly rising labor costs and related labor shortages.

By 1900 the panic created by the opening of the Mesabi, declining ore prices, and the depression of 1893 had abated on the Michigan iron ranges. The nation's economic recovery from the Panic of 1893 and renewed economic growth required all of the ore that all of the iron ranges could produce. Moreover, blast furnace operators had discovered that smelting the very fine-grained Mesabi ores required mixing them with coarser ores from the underground mines of the Upper



Slushing as initially applied by the Oliver Iron Mining Company, 1916-1920. A Uni-directional "Little Tugger" in the foreground, with a miner guiding a slip scraper in the background. The contents were dumped into the raise or chute in front of the tugger. The scraper required manual return to the mine face. (Lucien Eaton, "The Use of Scrapers in Metal Mines," Compressed Air, 26 (May 1921): 10067.)

Peninsula of Michigan or the Vermilion Range of Minnesota. Although blast furnace operators redesigned furnaces better to use Mesabi ores, they found they still needed a mix that included old-range ore for most efficient furnace operation.⁹

In addition, the continuing influx of cheap, plentiful immigrant labor from Europe helped underground mines keep their higher costs under control. In 1910, 89 percent of the labor force of Michigan's iron ranges was foreign born; an additional 9 percent had a foreign-born father.¹⁰

World War I, which began in 1914, ended the cheap, plentiful labor portion of the equation. By 1915 the demand for iron from the Western allies had begun to impact American ore production. Shipments from the Lake Superior district in 1916 exceeded the previous record year by 33 percent and composed around 80 percent of America's iron ore production.¹¹

Growing demand for ore—and the higher prices that ensued—proved a mixed blessing to Lake Superior's underground iron mines. Their owners and managers welcomed the growing demand and rising ore prices. But the demand for ore brought with it labor shortages and higher labor costs. Two factors contributed. First, mine operators increased production by adding shifts and opening new levels. This required additional labor and drove up wages. Second, the war in Europe ended large scale immigration, the traditional source of cheap mine labor.¹² Iron mines did not suffer alone; the mining industry generally faced severe labor shortages, leading the secretaries of the departments of Interior and of Labor to appoint a committee in 1917 to investigate mechanical devices to reduce the labor required for mining.¹³

To keep the miners they had, and hopefully attract new ones, mine operators across Michigan and Minnesota raised wages as immigration dried up and demand for ore exploded. At the underground Lake Mine near Ishpeming on Upper Michigan's Marquette Range, for example, wages rose by 10 percent on February 1, 1916, another 5

percent on May 1, and 10 percent more on December 15. Then in 1917 wages rose an additional 10 percent on May 1 and another 10 percent on October 1. At the nearby Morris-Lloyd mine wages rose by 41.2 percent between December 31, 1915, and December 31, 1917. Nor did the growth in wages cease in 1918. The Cleveland-Cliffs Iron Company, the largest producer on Michigan's Marquette Range, reported that average wages for all its mines in 1918 were 28.8 percent higher than for 1917.¹⁴ The Oliver Iron Mining Company, a subsidiary of United States Steel and the largest iron-ore mining company in the United States by far, saw similar increases. Between December 1, 1915, and December 15, 1916, the average daily wages paid to Oliver underground contract miners rose from \$2.80 to \$3.85, or over 35 percent. Wages rose even further in 1917 to around \$4.70 or nearly 70 percent above late 1915 wages.¹⁵

Making matters worse for the companies, the war also drove up the cost of materials used in mining—explosives, drill steel, timber, coal, and electricity.¹⁶ To some extent, the Lake Superior mine operators could raise ore prices to offset rising wages and material prices, but this flexibility vanished when the government fixed the price of iron ore following America's entry into the conflict in April 1917.

Rapidly rising wages posed particular problems for underground mines, for labor costs made up a much higher proportion of the cost of production underground than in open-pit mines. Underground operations could not be mechanized or increased in scale as easily or as rapidly. A 1902-1906 Minnesota study, for example, placed the cost of labor per ton of ore produced in open-pit mines at \$0.10, but four times higher, \$0.40 per ton, in underground and mixed mines. Labor constituted around 40 percent of the cost of ore production underground, only around 20 percent in open pits.¹⁷

Complicating things further, even high wages did not secure underground mines a good, stable workforce. On Michigan's Marquette Range in

1917, the managers of the Lake, Negaunee, Athens, South Jackson, Morris-Lloyd, and Stephenson mines complained of problems securing adequate labor.¹⁸ The American-Boston Mining Company, also operating on the Michigan ranges, reported that its labor situation was “getting increasingly difficult” and was a problem “that we seem not able to overcome.”¹⁹

In 1918 matters remained the same. The general manager of Cleveland-Cliffs’ mining operations reported a shortage of men “during the entire year.” The draft made things worse. Between the draft and enlistments in the military, Cleveland-Cliffs’ operations lost four hundred to five hundred men, well over 10 percent of its work force.²⁰ Observers described the Michigan labor shortage as “critical” in 1918, with the iron-ore producing Upper Peninsula needing five thousand additional miners, trammers, laborers, and carpenters.²¹

The end of World War I in November 1918 and the ensuing serious, but brief, post-war depression of 1920-21 temporarily alleviated labor shortages. But the problem soon returned.²² The culprits were Michigan’s booming automobile industry, and restrictive immigration legislation passed by Congress in 1921 and 1924 that ended the flow of immigrants on which Michigan’s underground iron mines had depended.

In 1923 M. M. Duncan, one of the country’s outstanding mine managers and, at the time, general manager of Cleveland-Cliffs’ mines, informed company president William G. Mather that the new immigration laws made the loss of the company’s younger and more efficient men to layoffs and the lure of the auto industry “serious, as they cannot be replaced by men coming from the old country” and since the American-born children of immigrants did not wish to work underground.²³ On the Menominee Range, the lease-holders’ representative for the Verona and Berkshire mines reported in 1923 that all mines in the district were short of men and blamed the shortage in part on the new immigration law.²⁴

Making matters worse, ore prices dropped sharply in the post-war period. Old Range Bessemer-grade ore, for example, which sold for \$7.45 a ton in 1920 had dropped to \$4.55 by 1928.²⁵ Declining ore prices, rising mine wages, and chronic labor shortages provided the “necessities” that stimulated the development of mechanical loading devices in underground mines to alleviate the labor-intensive tasks of mucking and tramping.²⁶

The Mucking and Tramping Bottleneck

Underground mining divides into a handful of basic operations: drilling, breaking (blasting), mucking (loading ore into mine cars), tramping (transporting the cars to the shaft), and hoisting. Between 1870 and 1910 most of the key elements in underground mining had seen significant technological improvement: drilling by the introduction of the two-man and later the one-man pneumatic drill; blasting by dynamite; tramping in part—but not completely—by underground locomotives; hoisting by steadily larger steam- or electrically powered hoists.

In 1910, however, miners still loaded ore into cars wielding No. 2 shovels and pushed the cars by hand to points where the ore could be dumped into cars that would be pulled by mule or locomotive, a process little changed from antiquity.²⁷ Mucking and tramping thus formed a “reverse salient,” or bottleneck. That bottleneck was serious because those operations comprised between 35 and 50 percent of a mine’s total labor costs.²⁸

Complicating matters, few men desired mucking and tramping jobs, and only those in outstanding physical condition could handle the tasks. A Finnish immigrant who mucked and tramped in a Michigan mine in the early twentieth century vividly described his experience: “My first days [in the iron mine] were a foretaste of hell. After making several trips from the diggings to the shaft, pushing a heavy tramcar, I was wretchedly tired. My thirst was unquenchable; sweat flowed in rivulets from my pores. My legs threatened to

give way, and my body became limp. . . . When lunch-time came, I was well-nigh prostrate. My food did not go down; my eyes saw dizzily; my ears rang; my heart pounded violently."²⁹

Not surprisingly, trammers—perhaps feeling they had little to lose—often proved troublesome employees. Michigan trammers went on strike in 1890 at the Winthrop, Volunteer, Norrie, and Cleveland Hematite mines; in 1892 at the Lake Superior mine; in 1894 at the Norrie; in 1897 at the Negaunee Mine; and in 1900 at the Winthrop Mine. And these strikes did not include the times they walked out jointly with other elements of the work force.³⁰

Periods of labor shortage seriously affected undesirable underground jobs like mucking and tramming, exacerbating an already serious production bottleneck. The superintendent of the Negaunee Mine at Negaunee, Michigan, on the Marquette Range, commented in 1904: "When labor is in demand trammers are difficult to keep, and the production of a mine is often curtailed by a shortage of this class of men."³¹

During World War I, shortages of trammers—as those who mucked and trammed were called on the Michigan ranges—were particularly severe. At the Cliffs Shaft Mine near Ishpeming and at the Republic Mine further to the west, both on the Marquette Range, superintendents reported a "scarcity of trammers, especially good trammers" in 1917.³²

Cleveland-Cliffs' mine managers continued to complain of shortages of trammers in 1919 and 1920.³³ Their complaints echoed elsewhere. In 1920 the *Engineering and Mining Journal* noted a shortage of unskilled labor in the mining industry, especially since immigrant labor was disappearing.³⁴ The assistant chief engineer of the Oliver Iron Mining Company, A. M. Gow, writing in 1920, noted that increasing wage scales and the shortage of men "able and willing to muck" were driving a search for loading machines underground.³⁵ And in 1924 Ward Royce, a mining engineer with Ingersoll-Rand, noted the increasing

scarcity of "the class of laborers" traditionally recruited for the work of mucking and tramming.³⁶

By the 1910s, superintendents of underground mines clearly recognized that mucking and tramming were serious bottlenecks. Those processes provided obvious targets for mechanization when the necessities of cost and labor reduction pressed underground iron mining. Mine mechanics, mechanical engineers, mining engineers, and mining superintendents responded by inventing a host of underground loading devices to speed up production and reduce labor costs in mucking and short-distance tramming. In the iron mines of Michigan, the slusher, or tugger-scraper, was the most successful of these devices.

Early Experiments

Technologically, slushing, or power scraping, is a simple concept and could have emerged decades earlier, since above-ground road and excavation contractors had developed the essential elements of the process well before 1900. The first records of power scraping underground occurred almost simultaneously in the Lake Superior iron mining region and in the Mountain West.

In 1898 Captain C. A. Anderson used a scraper powered by a small, compressed-air-powered hoist engine to pull fill into mined-out stopes in the Badger iron mine on the Menominee Range near Commonwealth, Wisconsin, just across the border from Michigan's Upper Peninsula. A short time later, Anderson unsuccessfully attempted to use the process for mucking—i.e., loading ore—at the Aragon Mine in nearby Norway, Michigan. His system failed for unknown reasons, but probably because it required manual return of the scraper.³⁷

At roughly the same time, or perhaps a few months earlier, U. A. Hough, directing construction of the Kellogg Tunnel for the Bunker Hill and Sullivan mines in Idaho, used a compressed-air-powered scraper to pull rock up a ramp and dump it directly into a mine car to speed up the

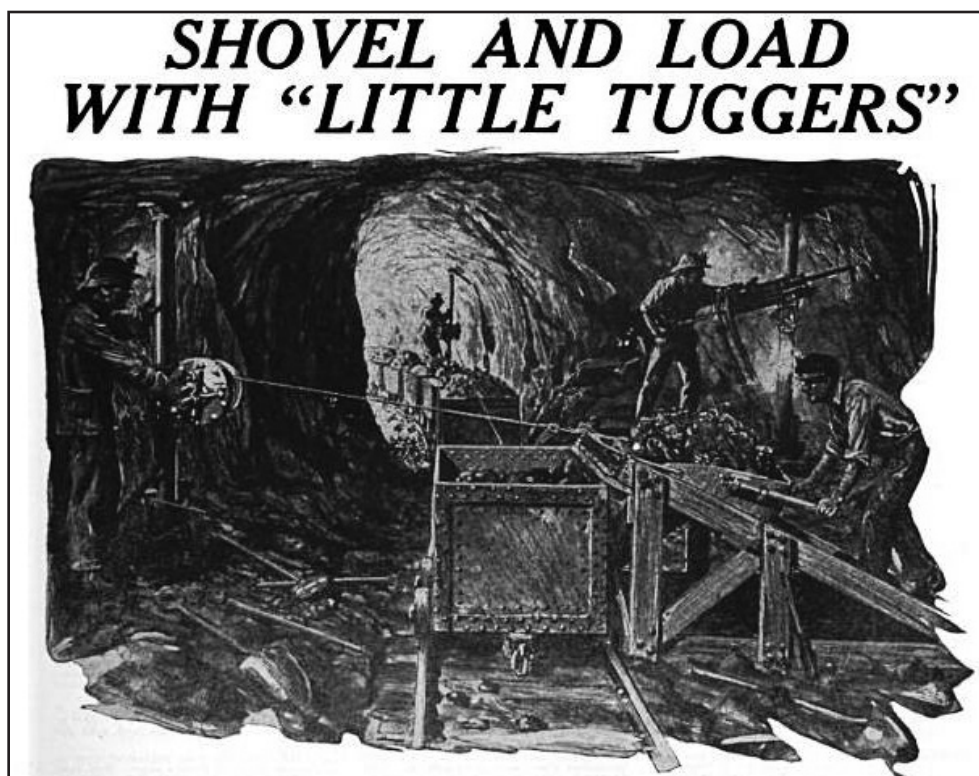
removal of excavated material.³⁸

In 1910, Nels Flodin of Marquette, Michigan, visited Gary, Indiana, with a group of mining engineers on a trip sponsored by the Lake Superior Mining Institute. Observing a man moving material with a horse and scraper, Flodin suggested that ore could be handled underground in the same way, but using the small air-powered hoist engines used to lift timber in mines instead of a horse.

On his return to Marquette, Flodin constructed a small model with a powered scraper which pulled a load up a ramp and dumped it directly into a mine car, much like Hough had done in 1898 in Idaho. Flodin showed his invention to some engineers, but they condemned it as be-

ing too simple and for not operating like a steam shovel by pushing into ore, rather than pulling it. Flodin, nonetheless, sought a patent for the device, received in 1912. Lake Shore Engine Works in Marquette received one order for the device, but never manufactured it.³⁹

Anderson, Hough, and Flodin's early work with scrapers did not diffuse. Several factors probably account for this. First, prior to World War I labor was relatively cheap in American mines, providing no incentive to invest capital in unproven devices that would upset traditional ways of doing things. Second, the portable hoist engines powering these early scrapers were large and heavy, making them difficult to move and use in the narrow underground workings typical



An Ingersoll-Rand advertising illustration for its "Little Tugger" hoist from Mining and Minerals, April 1921. The tugger, mounted on the column to the left, is shown pulling ore on a slip scraper and making use of a ramp to load it directly on a mine car. This was the form of scraper with which the Oliver Iron Mining Company began experimenting in 1916 and introduced in its underground mines on the Mesabi and Gogebic ranges in 1920.

of mines. Third, these early devices were power-driven in only one direction, requiring manual effort to return the scraper to the working face for the next scrape. This limited scraper size and speed and hence limited the device's labor-saving potential. Finally, these early units drew on an existing compressed air supply that would have been overtaxed if a new application like slushing suddenly came into wide use.

The Lake Superior copper mines—extraordinarily deep, facing competition from western open-pit mines, and plagued by war-time labor shortages—revived experiments with scrapers beginning in 1915. The primary vein in the deepest of these copper mines, the Quincy in Hancock, Michigan, had begun to flatten, so operators could no longer depend on gravity to bring broken rock from stopes down to drift level. In 1915 Quincy engineers introduced a bottomless scraper, powered by a specially designed, large, double-drum, reversible hoist, to speed up hard rock excavation in stopes. Results looked promising, and other Michigan copper mines soon began experimenting along similar lines.⁴⁰

Not surprisingly, the underground iron mines of the Lake Superior iron ranges, with similar problems, soon joined the experimental work, but they made use of a relatively new piece of mining equipment. In 1912 Ingersoll-Rand introduced a compact, simple, inexpensive, portable, pneumatic hoist engine called the "Little Tugger." The first truly portable hoist—originally designed to assist miners in moving timber supports, tools, and machinery underground—the 2.5 horsepower Little Tugger, weighing less than three hundred pounds, offered an ideal power source for other underground applications, including scraping.⁴¹

The soft hematite iron-ore deposits in Upper Peninsula Michigan tend to be thick and lens-shaped, enabling mining activities to take place at multiple levels in the same deposit. The predominant method of mining these thick deposits was some form of the caving system. In the caving system, mining companies worked ore deposits from

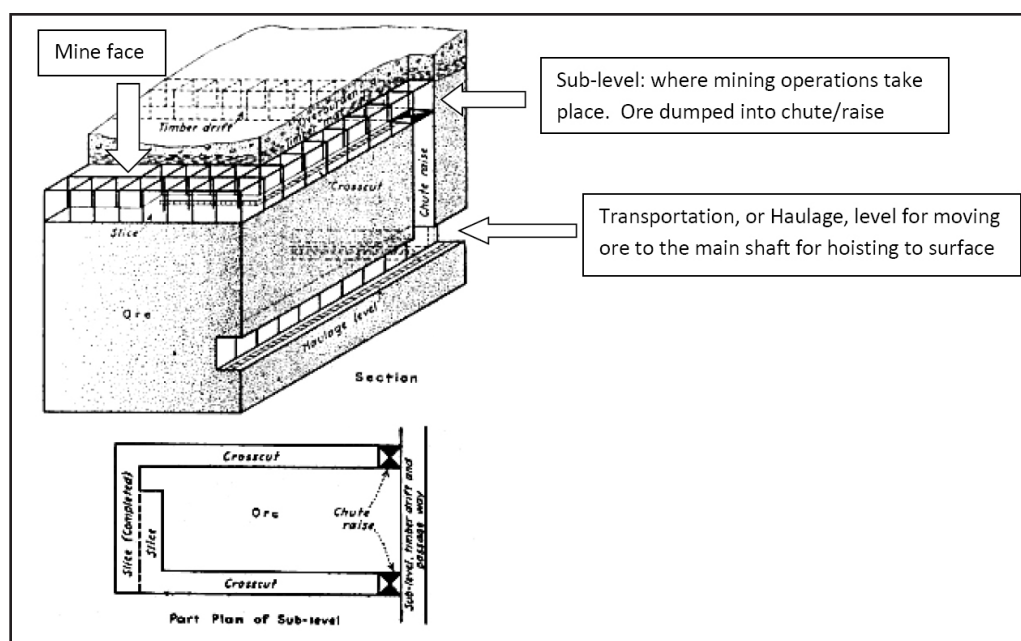
the top down, with the hanging wall allowed to cave in a controlled manner as miners worked the deposit downwards.

To make maximum use of gravity, miners constructed transportation or loading drifts every one hundred to two hundred feet. At ten- to thirty-foot intervals above the loading drifts, miners developed sub-levels, where ore was mined. Raises—shafts or chutes, usually sharply inclined—linked these sub-level drifts to the main, or loading, drift. Ore dumped into the raises from sub-levels could thus be loaded by gravity into mine cars in the loading drift for transport by electric locomotive to the shaft for hoisting. The thick deposits and the use of the caving system of mining proved ideal for the use of scrapers.

The Oliver Iron Mining Company, working with Ingersoll-Rand, began experimenting with slushing at its underground Spruce-Adams mines at Eveleth, Minnesota, on the Mesabi Range, in 1916. Oliver engineers recognized that Ingersoll-Rand's Little Tugger could be used to pull a scraper as readily as to lift timber.

In the system Oliver adopted, one miner operated a tugger, while another guided a slip scraper—a scraper with a bottom that carried its burden—pulled by the tugger's cable. At the end of a pull, the miner who accompanied the slip scraper dumped the scraper's ore into a raise or chute that emptied into mine cars on the loading level below, or dumped it directly into a mine car via a ramp. Because the Little Tugger had initially been designed to hoist material in mines, thus requiring power in only a single direction, the miner accompanying the scraper then had to manually pull it back to the mine face to repeat the process.⁴²

Although this system increased productivity over hand shoveling, it did not readily gain acceptance at the Spruce-Adams. The task of returning the scraper to the working face was arduous, and those doing the work could see no advantage to embracing the device. But Oliver persisted. In 1920 Oliver extended slushing work to all its underground mines on the Mesabi Range and to its



Schematic illustrating one form of mining using the caving system. The diagram shows only a single sub-level above the haulage level, although Lake Superior iron mines usually had multiple sub-levels above the haulage level. Note the distance that a loaded ore car would have to be trammed manually from the face to the chute/raise in the upper diagram. (Adapted from Ward Royce, "Scraping and Loading in Mines with Small Compressed-Air Hoists – I," Engineering and Mining Journal 112 (10 Dec. 1921): 925.)

deep underground mines on Michigan's Gogebic Range.⁴³

On the Gogebic, however, the Oliver system failed to catch on.⁴⁴ A writer for *Skilling's Mining Review* in 1920 reported that the slusher's slow manual return was a serious issue, and that the slip scraper did not work well in chunky ground. (Gogebic ore was chunkier than Mesabi ore.) "As far as iron mining is concerned," the writer declared, the use of the implement was "still in the experimental stage."⁴⁵

In response to the labor shortages and high wage rates of World War I, other companies with underground iron mines joined Oliver in experimenting with slushing. C. A. Anderson—who, as previously noted, had experimented with slushing as early as 1898 on the Menominee Range—introduced a scraper on the Cuyuna iron range of Minnesota in 1918.⁴⁶

At roughly the same time, the mining captain at the Isabella Mine on Michigan's Marquette Range combined a Quincy-type box scraper—a scraper with sides but no bottom—with a modified Little Tugger. Recognizing the need for a powered return, he installed a flange on the machine's drum and linked a return cable from the opposite side of the flange to the back side of the scraper through a sheave located near the mine face. He could then reverse the engine to drag the scraper back to the working face.⁴⁷

Lucian Eaton, superintendent of the Ishpeming district for the Cleveland-Cliffs Iron Company, was heavily involved in early experimentation with scrapers. In April 1917, working with Ingersoll-Rand, Cleveland-Cliffs officials installed a Little Tugger hoist engine on a column near a raise in the Negaunee Mine on the Marquette Range and used it to pull ore from the breast of a drift

after blasting. One miner operated the hoist and the other guided the scraper and then dragged it back to the breast for another load, much like Oliver system in the Mesabi underground mines.

After some work along these lines, company engineers installed a second hoist engine to pull the scraper back to the working face mechanically. It "worked fairly well at first," Eaton reported, but faltered due to insufficient air pressure in the mine. When air pressure dropped due to other draws, tugger operation became impossible. If air pressure could have been maintained, he thought, the scraper would have "proven a most successful method of tramming" for distances of seventy-five feet or less.

Cleveland-Cliffs also experimented with a single hoist with two drums. But after several months, the company discontinued the trial due to continued problems with air pressure, which prevented the system from averaging any more ore per man than the old method of hand shovel and tram car. Cleveland-Cliffs suggested to Ingersoll-Rand that it design a more powerful hoist without increasing its price and include a low gear to start the scraper as it took its load.⁴⁸

In 1919, Eaton began to experiment on his own with scrapers in his company's Cliffs Shaft and Holmes mines. The Cliffs Shaft featured hard, specular hematite, rather than the soft hematite of most regional iron mines. Specular hematite was a much more difficult problem for scrapers. It was heavy and broke into large irregular pieces. The slip scrapers employed in Oliver mines and the box scrapers used at the Quincy and Isabella mines did not work well with this material because the sides and bottom lacked sufficient weight to penetrate piles of hard specular ore. Moreover, existing hoist engines were both underpowered and consumed too much air for Cliffs Shaft work.

Drawing from contemporary scraper trials carried out in the southeast Missouri lead district, Eaton designed a sideless, hoe-type scraper with teeth to scrape Cliffs Shaft ore. Eaton also tested

both compressed-air and electric scraper motors, various sizes of wire rope, and different labor arrangements. Eaton's promising experiments terminated when the Cliffs Shaft Mine closed temporarily in December 1920 due to the depression of 1920-21.⁴⁹ He continued his work with scrapers at the soft-ore Holmes Mine, introducing a hoe scraper of different design to deal with its lumpy, soft ore in 1920.⁵⁰

Several early commentators indicate, without providing details, that other iron mines, besides those of Oliver, Cleveland-Cliffs, and the Isabella, experimented with scrapers prior to 1920, but note that "nearly all" abandoned the idea.⁵¹ Labor's response was one problem. Generally, mines in the Lake Superior district operated on the contract system. Teams of miners "contracted" on a monthly basis with mine management to drill, blast, timber, muck, and tram so many tons of ore for a set price per unit (feet drilled, mine cars delivered to shaft, etc.).⁵²

Even if slushing had the potential to increase their output, miners suspected it would simply mean that operators would lower the contract price proportionately. They would gain nothing. Thus, while the heavy work involved in carrying the scraper back to the mine face was undoubtedly one issue in the failure of early experiments, the initial failure of mining companies to create incentives for labor was another, and perhaps more serious, issue.⁵³

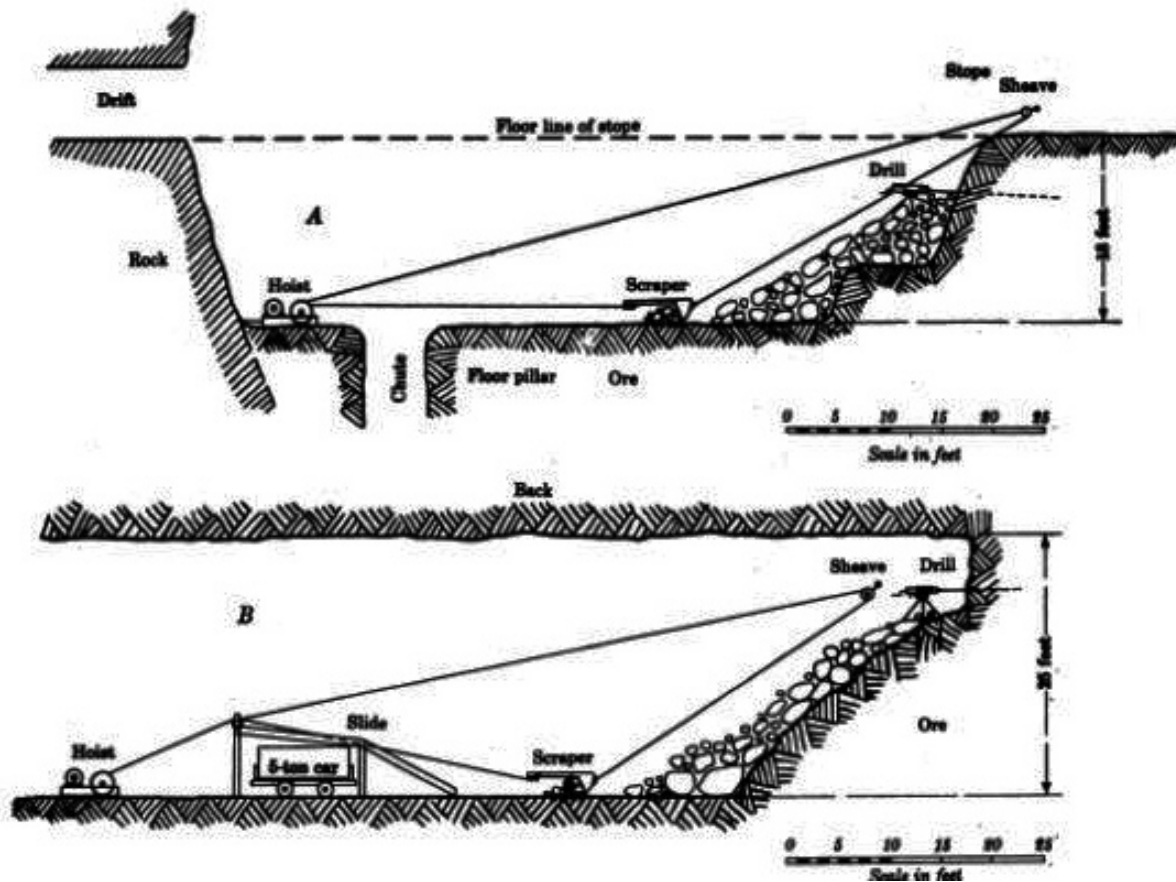
Early experimenters undoubtedly encountered other problems as well. The Oliver slip scraper, for example, was too light to penetrate the heavier, thicker ore of the Michigan ranges. Each mine operator had to come up with a scraper of the right weight, pulling power, design—sides or no sides; teeth or no teeth; bottom or no bottom—and blade angle to suit that mine's ore. Simply adopting a scraper design from another mine was a path to failure. Thus Oliver engineer A. M. Gow, in a review of underground loading machines, declared in 1920 that "the No. 2 shovel still holds its own."⁵⁴

The Turning Point

In many ways, however, 1920 marked a turning point. In 1920-21, responding to feedback, several mining equipment companies brought out more powerful, double-drum, reversible hoist engines, specifically designed for use with scrapers, instead of simple adaptations of an engine designed to hoist timber. Ingersoll-Rand in 1920 introduced the Little Tugger 6H, a six horsepower unit operating at an air pressure of sixty-five to eighty pounds and still light enough to be semi-portable. Two other companies now entered the

field: the Denver Rock Drill Co. and the Sullivan Machinery Company. Both introduced reversible, double-drum hoists that competed with the improved Little Tugger and had some additional features, including the ability to operate more effectively at lower air pressures and with faster wire rope speeds.⁵⁵

In 1920, also, Oliver expanded its slushing work beyond the Spruce-Adams mine to its remaining Mesabi underground mines and to its deep Gogebic Range underground mines.⁵⁶ Meanwhile, in Marquette Range mines, Eaton continued the experiments he had initiated in



Diagrams illustrating double-drum, reversible scraper operation. Sketch A shows a scraper-hoist in operation in a sub-level of an iron mine using the caving system. The hoe-type scraper pulls the ore from the mine face on the right to a chute, or raise, leading to a transportation level beneath. Sketch B shows a tugger-scraper pulling ore directly onto a mine car. The hoists, or tuggers, in these diagrams are "double drum," that is, they have a tail rope wrapped around a second drum on the tugger, designed to pull the scraper back to the mine face. (C. F. Jackson, Some Notes on Underground Transportation [U. S. Bureau of Mines Information Circular 6326] (Washington, D.C.: Bureau of Mines, 1931), Figs. 29 A and B.)



A double-drum scraper in action. The hoist engine is in the background. The scraper is pulling a load of ore toward a raise (covered with bars just in front of the scraper). Rope for power return is visible at the back of the scraper. (Charles E. Van Barnaveld, Mechanical Underground Loading in Metal Mines [Bulletin, University of Missouri School of Mines, Technical series, v. 7, no. 3] (Rolla, MO: U. S. Bureau of Mines and Missouri School of Mines and Metallurgy, 1924, 252.)

1919. Observing these developments, in August 1920 *Skellings Mining Review* called the use of slushers “the most important development of late years in underground mining,” and in early 1921 *Compressed Air Magazine* declared that the slushing system of mining was “the one great underground mining development of the last year.”⁵⁷

So rapidly did work with the tugger-scraper combination spread that in May 1921 Eaton commented that there was “hardly a mining district where experiments are not being made and scrapers of various types being tried.”⁵⁸ Among those districts was the nearby Michigan copper mining district. James MacNaughton, general manager of one of Michigan’s great copper mines, the Calumet and Hecla, reported in *Engineering and Min-*

ing Journal in January 1921 that his company was installing the new device “as rapidly as possible” where appropriate, and that he expected to operate his mines with “decidedly fewer trammers” when economic conditions improved.⁵⁹

The rapid diffusion of powered scrapers hit a temporary road block when the depression of 1920-21 curtailed operations at many mines on the Michigan and Minnesota iron ranges. But as the nation’s economy improved, adoption came very rapidly. In late 1922, for example, the Oliver Iron Mining Company, after two years of testing and evaluation, announced it would adopt scraper mining wherever conditions permitted in its underground mines.⁶⁰

While Oliver continued to use the single-

drum engines in its Mesabi Range mines, its efforts succeeded on the Gogebic Range only with the newer, faster, and more powerful reversible, or double-drum, units, and a different scraper design. By 1923, scraper mining was “firmly established” in the Oliver Iron Mining Company. Oliver had eighty-two single-drum and eight double-drum slushers at its underground mines on the Mesabi Range. In its deeper underground mines on the Vermilion Range in Minnesota and on the Gogebic Range in Michigan, the company had sixty-four double drum scrapers.⁶¹

Nor was Oliver alone in the rush to use scrapers for loading ore. In 1922, Eaton declared that scrapers in the soft-ore mines of the Lake Superior region were “now an assured success.”⁶² And in 1924 a writer in the *Engineering and Mining Journal* declared the use of scrapers “now relatively widespread.”⁶³

The key factor influencing rapid adoption was a growing body of data indicating that powered scrapers offered significant cost savings over traditional mucking and tramping operations. Oliver’s early work with scrapers at the Spruce-Adams mines, for example, yielded a 23 percent increase in tons handled per miner per shift with the manual return system.⁶⁴ At the Utica Mine on the Mesabi, Oliver in 1923 reported a 50 percent increase in output and a 23.5 percent savings in cost per ton.⁶⁵ Boyd, reporting on Oliver’s work to the Lake Superior Mining Institute in 1923, claimed double-drum units were yielding ever bigger production increases per shift: from 63 to 103 percent. Already by 1923, scrapers handled a significant portion of the work once done by Oliver muckers and trammers: 62 to 100 percent in their Mesabi underground mines, 24 to 65 percent in their deeper Vermilion and Gogebic Range mines.⁶⁶

On the Michigan ranges, the original Oliver system with its manual-return scraper never caught on. However, the newer, more powerful, faster winding, double-drum systems with heavier and higher-capacity scrapers were rapidly adopted

there. In 1921 one Gogebic Range mine reported that scrapers allowed it to develop ore faster than ever before and that production was “about double that of hand shoveling methods.”⁶⁷ A 1924 Bureau of Mines-sponsored study asserted that overall experience on the Gogebic indicated an increase of 50 to 75 percent in the tonnage delivered per man per shift and sometimes more, and a decrease of 25 to 30 percent in the cost of ore delivered at the chute, as well as more satisfied and better paid miners.⁶⁸

On Michigan’s Marquette Range, Lucien Eaton’s standard answer when asked about saving using scrapers was: “Roughly speaking, half the cost of shoveling and tramping.” In many cases, he added, the savings were even greater. He reported that at the Holmes Mine scrapers increased the footage excavated in sub-levels by 40 percent over a year, and increased tons per shift by 47.5 percent.⁶⁹ Tests, probably carried out by Eaton but reported by Van Barneveld of the Bureau of Mines in 1924, yielded similar results. At the Cliffs Shaft hard-ore mine scraper loading yielded 14 tons per man per shift versus 7.2 tons by hand loading. At the soft-ore Maas Mine tests yielded 13.07 tons per man per shift using scrapers, 8 to 9 tons using shovels.⁷⁰

Rapid Diffusion

With results like these flooding in, installation of scrapers went forward rapidly on all three Michigan iron ranges in the mid-1920s. The Gogebic Range led the shift. Already by 1924, according to a Bureau of Mines study of underground mechanical loading devices, “hardly a mine on the Gogebic Range [was] not using scraping in one form or another.”⁷¹ In 1926 Carroll Taylor reported the same: “practically every mine” on the Gogebic iron range used slushers.⁷² The Castile Mining Company, on that range, reported in 1926 that it had altered its way of laying out its mine in order to use slushers to best advantage.⁷³ John Berteling, mine superintendent

for Youngstown Sheet and Tube, reported that same year that without the double-drum slusher he could not have mined the Gogebic's North Palms ore body at a profit.⁷⁴ The engineers in charge of the Montreal Mine on the Wisconsin side of the Gogebic Range declared in 1929 that the scraper method of handling broken ore and rock had "entirely displaced hand shoveling and hand tramming" at their mine.⁷⁵ Overall, iron ore production on the Gogebic rose from 2.91 tons per miner per day in 1923 to 5.96 tons in 1929, an increase that several observers attributed largely to the introduction of scrapers.⁷⁶

The earliest working-scale scraper installations on the Marquette Range came in 1922, two years behind the Gogebic. As noted earlier, Lucian Eaton, a Cleveland-Cliffs district superintendent, experimented extensively with scraper loading beginning in 1917. At the Cliffs Shaft Mine he encountered problems because existing scrapers were too light and could not penetrate heavy rock; complicating matters, the early Ingersoll-Rand hoist engines did not have sufficient power to pull heavy scrapers, making development of the equipment "a difficult problem."⁷⁷

The new hoist-tugger engines, designed especially for scraper use, which came out in 1920 and 1921 turned the tide. Cleveland-Cliffs began to

install scrapers in significant numbers in 1922-23. In 1923 Eaton put six scraper-hoists into service at the Cliffs Shaft, reporting that they had "aided materially in reducing the cost of tramming" and suggesting that more might be added "in anticipation of a shortage of trammers again."⁷⁸ The superintendent of the Athens Mine reported in 1924 that the results obtained from using tugger-scrapers were "very satisfactory." The following year he reported that the contract rate per car for stoping had been reduced from \$1.84 in 1923 to \$1.57 in 1925, "due principally to the scraper method of mining." The manager of the Maas Mine reported that "quite satisfactory results" had been obtained by using a slusher, giving "consistently . . . a much higher product per man day than hand shoveling."⁷⁹

In the Marquette Range's North Lake District, Morris-Lloyd's superintendent announced in 1925 that scrapers had "worked out wonderfully well for us," increasing the efficiency of miners almost exactly 90 percent. He concluded that "scrapers were the greatest single factor in reducing costs in this district."⁸⁰ By 1927 scrapers handled 100 percent of the mine's ore loading. The nearby Barnes-Hecker mine installed its first scrapers in 1924. When the mine flooded in early 1926, killing 51 miners, scraper teams were already loading



A tugger-scraper on the seventh level of Cleveland-Cliffs' Morris Mine in the 1920s. The electrically powered drum that made up the tugger part of the combination is on the left; the hoe-type scraper with teeth that the tugger's cables pulled back and forth is on the right. (Courtesy of the Michigan Tech Archives and Copper Country Historical Collections, Houghton, Michigan.)

95 percent of its ore.⁸¹

The scraper arrived on the Menominee Range at about the same time it found extensive application on the Marquette Range: 1922-23. The Caspian Mine near Iron River introduced the device in late 1922 after some prior experimentation. By 1924 the mine had twenty. Output rose from 7.41 to 12.53 tons per man per shift, a saving of 18.7 cents a ton over hand shoveling.⁸² At the Osana and Wauseca mines near Iron River in late 1922 or early 1923 George Newton began using a scraper mounted on a ramp-platform combination to load ore directly into cars. The combination—called an Osana loader—would find extensive use in subsequent years.⁸³

The Rogers Mine in the same region began using scrapers in 1922 or 1923. The mine's operators needed not only more tonnage per man per shift, but also some way to mine areas more rapidly to avoid having to re-timber due to a heavy, wet overburden. The mine's early experiments with electrically driven scrapers failed due to the wetness of the mine, but an air-powered version with an enlarged air line worked quite well. By 1926, the Rogers loaded mainly with scrapers: operating twenty-one tugger crews and only five hand crews while on two shifts. Hand-shoveling crews averaged 8.8 tons per man per shift; scraper-equipped crews averaged almost double that: 16.05 tons. In 1927 the Rogers used twenty-one crews; twenty used scrapers and only one used hand methods.⁸⁴

In turning to scrapers using air pressure in the mid-1920s, the Rogers' experience was an exception. While before 1924 scrapers were almost always pulled by compressed air, after 1924 electrically driven hoists became steadily more popular.⁸⁵ Compressed-air-powered slushers put more demand on compressed air systems already hard pressed to supply sufficient air to drills. Early electrical scraper-hoist motors were too heavy to compete with compressed air units, but by 1924 lighter, electrically-powered double-drum slushers, which were cheaper than compressed-air slushers to operate, had begun to penetrate un-

derground.⁸⁶

Because expanding electrical systems was usually easier than expanding compressed-air systems, the shift toward electric-powered tuggers was rapid. At the Morris-Lloyd mine on the Marquette Range, for example, the superintendent commented that the captains and bosses "all" preferred electric to air tuggers because they pulled a larger load, did it more smoothly, and would take a greater overload without trouble.⁸⁷ The Negaunee Mine had only air-operated tugger units prior to 1926, but in 1926 its operators brought in eight electric and only two air-operated units. By January 1929 electric slushing units outnumbered air slushing units at the Negaunee twenty-six to seventeen.⁸⁸ In 1929 Cleveland Cliffs decided to adopt the fifteen-horsepower electric scraper as its standard and began to phase out its air-powered hoists.⁸⁹

Gradually, the size of scraper equipment grew, especially as electrical units came into vogue. The early slusher units depended on the 2.5-horsepower air-powered Little Tuggers of Ingersoll-Rand, with their 24-inch-wide scrapers that moved 3.5 cubic feet of material at a time. By 1930 or shortly after, tugger engines had reached an average output of 15 to 20 horsepower, with scrapers averaging 36 to 48 inches in width with a load capacity of around 10 to 14 cubic feet. For special applications—like dragging hard specular hematite—power and scraper size could be much larger.⁹⁰ The more powerful tugger engines increased the economical scraping distance to 150 to 200 feet and beyond compared to the 50 to 75 feet typical with early slusher units.⁹¹

Mine operators who adopted scrapers soon discovered they had additional advantages. Savings came not only from the reduced labor required for mucking and tramming. Laying track and bringing mine cars into each sub-level was no longer necessary, since the scraper pulled ore to raises for gravity loading on levels below. Because the scraper accelerated the pace at which material could be removed, it also reduced timbering

expenses. In mines where the ground was heavy and wet, scrapers often eliminated the need for re-timbering. And scrapers reduced the wear and tear on miners, leaving them fresher for their other tasks—drilling and blasting and timbering.⁹²

Practically unknown before 1920, scrapers came into general use with extraordinary rapidity. Lucien Eaton reported in 1925 that the use of scrapers in the soft-ore mines of the Lake Superior iron districts was “now well established.”⁹³ In 1928 Robert Matson of the Michigan College of Mines estimated that Michigan’s iron mines had already installed 400 electric and 150 air-powered slushing units and declared that the scraper method was “well established in the iron mines of the Lake Superior district” and had displaced hand shoveling in all but a few places.⁹⁴ Bureau of Mines investigators found the same thing: by 1930, in less than a decade, scrapers had all but displaced hand shoveling and short-distance tramming in Lake Superior underground mines.⁹⁵

The very rapid embrace of the scraper loader on the Michigan iron ranges—taking as little as three years on some ranges and less than a decade in the Lake Superior district as a whole—vividly illustrates one of the factors that enabled Michigan’s underground mines to remain competitive with the Mesabi’s open-pit mines for nearly three quarters of a century. Although scraping underground appeared simultaneously outside of the Lake Superior region in 1898, and other mining districts experimented with, adopted, and used scrapers in the 1920s, nowhere else were they used as extensively.⁹⁶ Indeed, from 1923 to 1930, almost 80 percent of scrapers installed in underground mines were installed in iron mines.⁹⁷

Creating New Necessities

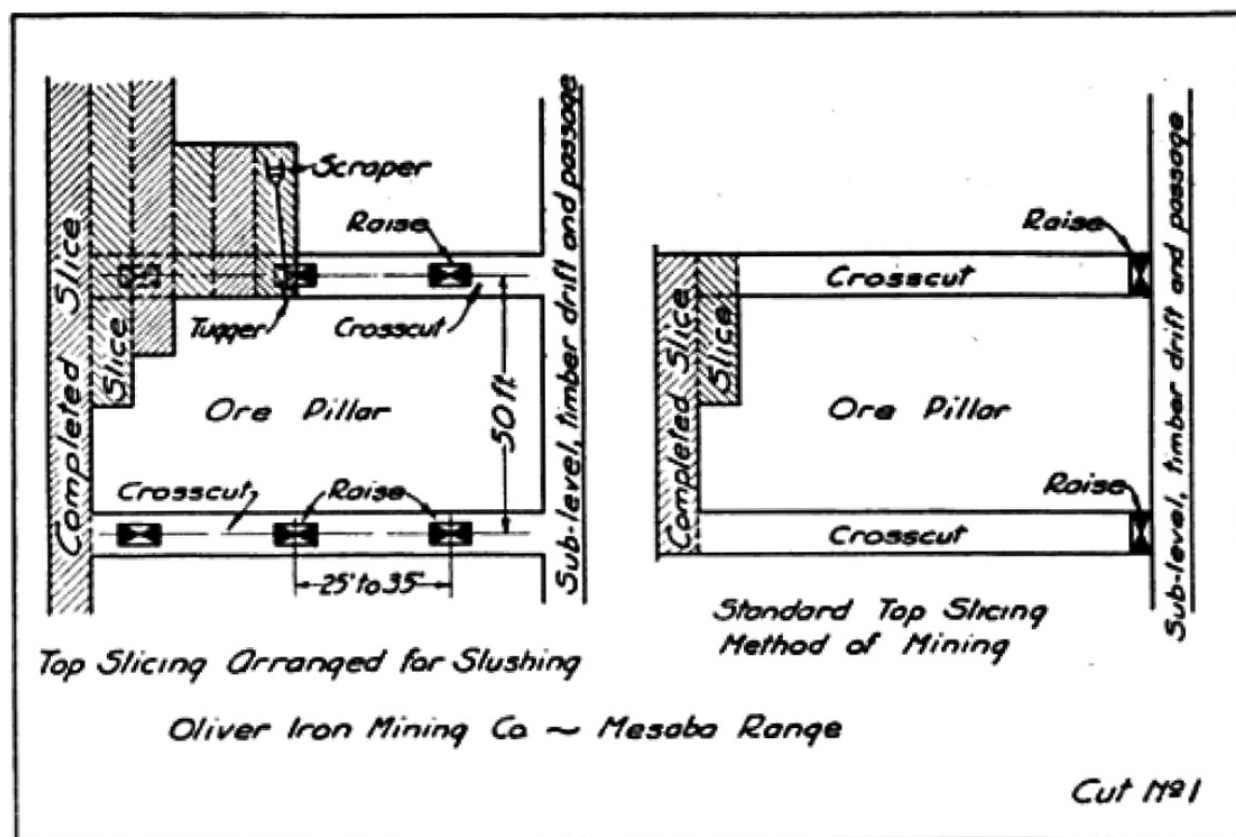
Since its invention and wide adoption were driven by the need to combat rising labor costs, growing labor shortages, and falling ore prices induced by the competition of low cost, open-pit, steam-shovel mines, the tugger-scraper supports

the notion that “Necessity is the mother of invention.” Somewhat less known, except to historians of technology, is Mel Kranzberg’s inversion of that old saying to “Invention is the mother of necessity,” suggesting that inventions themselves create new necessities. Indeed, the adoption of slushing created new necessities. An observer noted in 1924 that “the undoubted success of . . . scraper and slusher mining has led many mining companies to alter their methods in order to avail themselves of the scraping system with its many advantages and low costs.”⁹⁸

For example, iron mines had to be laid out in new ways to make the best use of scrapers. With hand mucking and tramming, raise location was not a critical issue. However, the early scraper systems could pull ore economically only about fifty feet, so to make the best use of scrapers mine operators had to place chutes within fifty feet of working faces. This meant mines needed more raises than previously.⁹⁹ Traditionally, iron mine operators had taken out sections of a deposit being worked in parallel and perpendicular slices. One of the new methods adopted to accommodate power scraping was a radial pattern—taking slices out like the movement of the hands of a clock, with the pivot point centered on the raise to which material would be scraped.¹⁰⁰ This avoided having to drag ore around sharp turns.

Another problem was that miners with scrapers often brought ore to cars faster than locomotives could hauled it off, and clogged raises with ore. Locomotive tramming suddenly became the bottleneck instead of mucking and hand tramming. Some mine operators responded by bringing in bigger cars to speed up loading.¹⁰¹ Others adopted new methods of storing ore underground to avoid work stoppages, such as a storage sub-level to handle ore before loading it on cars or storage trenches on the main transport level.¹⁰²

In addition to the technical changes made necessary by the coming of scraper loading, changes also had to be made in how operators dealt with labor. To get labor to accept using the



One example of mine reconfiguration made necessary by the full-scale use of scraping. Note the increased number of raises needed as manual tramming was abandoned for scraping. Later arrangements with more powerful scraper engines and larger scrapers increased the distance between raises. Note also the different approach to mineral excavation made advantageous by the use of scrapers (Ford E. Boyd, "Slushing Practice in the Mines of the Oliver Iron Mining Company," Proceedings of the Lake Superior Mining Institute 23 (1923): 70.)

device—initially a major problem—companies had to revise their contracting systems to share the cost savings engendered by the new technology. As companies introduced scrapers, they also typically introduced new and lower contract rates per car to reflect the greater number of cars they expected to see loaded. After early fumbling, mine operators learned to set the price paid per car at a level that enabled miners using scrapers to earn roughly 20 percent more than they had with shovels, thus sharing in the savings mine operators had garnered in reduced mucking and tramming costs.¹⁰³

Some companies also found it necessary to alter other elements of their contracting systems.

In many Michigan underground mines, a contract gang of two men worked at a single opening per shift. To accommodate the new technology, with its faster rate of mucking and tramming, some operators introduced gangs of three men per shift, but assigned them two openings. One man drilled and blasted both faces, while the other two handled mucking and timbering—a division made possible by mechanizing the mucking process with scrapers.¹⁰⁴

The Alternative Technology: The Shovel Loader

The use of tugger-scrapers in underground

mining was but one path pursued by underground operators in the period from 1895 to 1930 to reduce dependence on labor. Several underground iron mines experimented with conveyor-type loaders, but in the end they did not hold up well in the abrasive atmosphere.¹⁰⁵

A more successful alternative was the shovel-loader, an even more direct substitute for a miner with a shovel than the tugger-scraper. Shovel-loaders were mechanically powered devices that imitated the action of a human with a shovel: successively pushing a blade into ore, lifting it, and then throwing it into a mine car.

The first experimental shovel-loaders appeared in the southeast Missouri lead mines in 1912, and interest grew in parallel with interest in scrapers for much the same reasons: rising demand for metals, rising labor costs, and shortages of labor. Between 1910 and 1930 inventors in widely scattered mining districts introduced a variety of shovel loaders, each operating in a slightly different manner, among them the Keystone, Butler, Conweigh, Myers-Whaley, Armstrong, Hoar, and Mayne. Van Barneveld, in his 1924 review of mechanical underground loading, identified twenty-three models in a host of configurations.¹⁰⁶

Generally, mine operators initially favored the shovel-loader, with its more direct imitation of a human mucker, over the scraper-loader or slusher.¹⁰⁷ The same can be said for operators of iron mines in the Lake Superior district. The Judson mine on the Menominee Range and the Maas Mine on the Marquette Range tried out mechanical shovels in 1915, as did others in 1916.¹⁰⁸ Several mines installed the Hoar shovel-loader before the end of World War I, a design introduced on the Mesabi Range.¹⁰⁹

The Montreal Mine on the Gogebic Range began using Hoar shovels regularly in 1920, reporting that under similar conditions the cost of teams using the Hoar was \$7.86 per foot mined compared to \$12 for shovel teams.¹¹⁰ The Barnes-Hecker mine on Michigan's Marquette Range had three Armstrong shovel-loaders in 1919; that

same year the Holmes Mine tried a Hoar loader.¹¹¹ In 1919, *Skillings Mining Review* declared that the shovel-loader had "come to stay" in Lake Superior underground iron mines.¹¹² But by the mid-1920s, the shovel-loader had been completely overshadowed by the scraper-loader.

The Negaunee Mine of the Cleveland-Cliffs Iron Company exemplifies in microcosm the competition between the two technologies in underground iron mines. In 1917, working with Ingersoll-Rand, Cleveland-Cliffs made initial experiments with a slushing outfit, but found that the technology, though promising, yielded results no better than mucking and tramming by hand. In 1920 the mine's management turned to shovel-loaders, installing a unit developed locally by John Mayne of Negaunee and specifically intended for sub-levels of soft hematite mines.

Mayne designed his mechanical shovel to be inexpensive to build, simple to operate, and very easy to repair, three features not often found in shovel-loaders. From May 1921 to April 1922 ore drifting and stoping contractors at the Negaunee Mine using the Mayne loader produced 93.5 percent more per man than the mine's average. Impressed, mine officials purchased and installed more of the devices; by December 1922 the Negaunee Mine had five Mayne loaders in service.¹¹³ In 1924, two years later, nine Mayne loaders handled nearly a quarter of the mine's ore.

In contrast, after the failure of 1917, the Negaunee mine's management did not install another slusher until 1922. In 1924 the mine had only three slushers, compared to nine Mayne loaders. But the slushing units worked so well that the following year scrapers outnumbered shovel-loaders eleven to nine, and by the year after, 1926, the mine had twenty-one scrapers, which loaded 45 percent of the mine's ore, compared to ten shovel-loaders, loading only around 22 percent.

In 1927 the mine's management decided to replace the Maynes as they wore out with scrapers. In March 1928 the mine retired its last Mayne shovel-loader. By December the mine's scrapers,



A Mayne shovel loader at Negaunee Mine in 1924. One of many types of Shovel loaders introduced across the United States between 1910 and 1925, the Mayne was designed to be as cheap and simple as possible to combat high first cost, excessive down time, high maintenance costs, and excessive space requirements – four common disadvantages of contemporary shovel-loaders. It worked effectively in soft hematite ore but proved unable to compete with the even cheaper and simpler slusher units. Pneumatic cylinders drove the shovel into the ore pile, pulled a shovel load back out, and then threw the load like a manual shoveler into the ore car shown in the background. (George R. Jackson, “The Mayne Loader,” Proceedings of the Lake Superior Mining Institute 22 (1922): 146.)

now numbering fifty-eight, loaded nearly all the mine’s ore. In six short years, 1923 to 1929, slushers employed grew from one to fifty-eight and completely displaced not only hand shoveling but shovel-loaders as well.

Like Cleveland-Cliffs at its Negaunee Mine, other iron mining companies also shifted from shovel-loaders to scraper-loaders. On the Menominee Range, for example, an engineer reported in 1923 that the only type of machine that had met with “any success in this district” was the scraper.¹¹⁴ Oliver accepted power shovels in main-level drifts, but, because of high first cost and mainte-

nance issues, found the simple scraper “to be most satisfactory” in most areas of its mines.¹¹⁵ In 1928 Matson of Michigan’s College of Mines noted that he had visited eighteen mines to study scraping practice and found only three using shovel loaders.¹¹⁶

In a way, the triumph of the simple, inexpensive tugger-scraper over the more complicated and expensive mechanical loader is an application of Occam’s razor to mining technology. Occam’s razor is a widely used philosophical principle, often applied in the sciences, that maintains that among competing hypotheses, when the available data is

Year	# Scraper Loaders (% Ore Handled)	# Shovel Loaders (% Ore Handled)
1917	1 [Scraper test unsuccessful]	0
1920	0	1
1922	1	5
1923	1	7
1924	3	9 (22.4%)
1925	11	9 (20.2%)
1926	21 (45%)	10 (22%)
1927	35 (57%)	4 (15%)
1928	43 (83%)	0 [after 3/1928] (1%)
1929	56 (97.5%)	0
1930	All ore moved to raises by scraper	0

Scraper-Loader (Slusher) and Shovel-Loader Use, Negaunee Mine, Marquette Range, Michigan, 1917-1930. (Compiled from scattered remarks in the Negaunee Mine section of the "Agent's Annual Report, Mining Department, Cleveland-Cliffs Iron Company, 1917 to 1930," Cleveland-Cliffs Papers, Archives of Michigan.)

not sufficient to settle the issue, the simplest hypothesis should be selected. This same principle, suitably modified, can be applied to technology: when competing technologies yield comparable results, adopt the simplest and least expensive.

Scraper-loaders and shovel-loaders delivered roughly comparable savings over hand shoveling. But, as Oliver engineer A. M. Gow noted in 1920, part of the appeal of the scraper or slusher was its "extreme simplicity."¹¹⁷ Van Barneveld of the U.S. Bureau of Mines, after an extensive review of shovel-loaders, conceded that scrapers represented "the smallest investment and offer[ed] the greatest mobility and flexibility."¹¹⁸

Other factors, of course, entered in. The shovel-loader typically required considerable head room for its throwing action, often restricting it to development work in main transport passages rather than use in the more numerous, smaller, often cramped, stopes, drifts, and sub-levels where iron miners extracted ore. Scrapers, with their small, portable engines, could better handle cramped work. Shovel-loaders had a higher first cost. In 1921 Eaton put the cost of

a tugger-scraper at \$750 to \$1,500 and a shovel loader at \$3,000 to \$14,000.¹¹⁹

Other elements added to the shovel-loader's higher first cost. Using shovel-loaders required laying track to bring mine cars into the sub-levels found in most iron mines; using scrapers did not. The abrasive atmosphere in iron mines, combined with the shovel-loader's more complicated mechanisms, meant higher maintenance costs, more frequent downtime, and the need to hire expert mechanics to service the machine.¹²⁰ The simpler slusher was much more durable and could usually be repaired by the miners themselves.¹²¹

The table above graphically illustrates the triumph of the slusher, or scraper loader, over the more complicated shovel-loader. Even in 1923, the earliest date for which such data exist, mining equipment manufacturers sold around fifteen times more scraper-loaders than shovel-loaders to American iron mines, and that margin had increased many fold by 1929. The introduction of a smaller, more reliable shovel-loader in 1932—the Finlay loader—came too late to have a significant impact on underground iron mines.¹²² By then

Year	Scraper loaders*	Shovel loaders
1923	216	17
1924	200	5
1925	290	7
1926	202	6
1927	340	4
1928	287	2
1929	569	15
1930	266	3
1931	81	0
1932	76	0
1933	37	0
1934	44	2
1935	89	3
1936	127	0
Total	2,824	64

Based on reports by manufacturers to the U.S. Bureau of Mines.

*Includes hoists intended for scraping or complete units (hoist engine + scraper).

Scraper Loaders and Shovel Loaders Sold to Iron Mines in the United States, 1923-1936 (From N. Yaworski et al., Technology, Employment, and Output per Man in Iron Mining [Report No. E-13] (Philadelphia: Works Progress Administration and Department of the Interior, Bureau of Mines, 1940), 154.)

the slusher had already triumphed.

Underground Slushing in the Lake Superior Iron Mines

Scraper-loading, or slushing, was an American mining innovation that reached its greatest development in the Lake Superior iron ore ranges and diffused from there worldwide.¹²³ To stay alive in the face of low ore prices precipitated by the “steam shovel” mines of the Mesabi, and the high wages, declining ore prices, and labor shortages of the period from 1915 to 1930, the owners and managers of Upper Michigan’s iron mines had to take advantage of every possible cost-saving.

One response was the rapid adoption of slushing. Before 1920 scraper mining was practically non-existent in Michigan mines; by 1930 it had completely displaced hand shoveling. The magnitude of the productivity gains yielded by the rapid adoption of slushers in the 1920s is suggested by

data collected by the Works Progress Administration in the 1930s. Between 1916 and 1920 output in the underground iron mines of Michigan and Wisconsin averaged 0.352 tons per man hour, varying no more than about 4 percent from that average. However, during the 1920s, the period in which iron mines rapidly embraced scraper-loaders, output per man hour rose steadily. In 1930 the average production at Michigan and Wisconsin’s underground iron mines hit 0.590 tons per man hour, almost 70 percent greater than the 1915 to 1920 average. The labor-savings impact of the slusher can be demonstrated in another way. In 1919 and 1929 ore output from Michigan iron mines was nearly identical, around 15,460,000 tons. In 1919, however, employment in Michigan iron mines stood at 17,709, while in 1929 the mines required only 9,308 men to achieve the same production.¹²⁴

Admittedly, the scraper-loader was not solely responsible for either the productivity gains or

the labor savings in underground iron mines in the 1920s. Other innovations contributed, such as electrification, improved drills, and improved mining schemes. But contemporary observers regarded the introduction of the powered scraper as *the primary* factor. C. F. Jackson, senior mining engineer at the Bureau of Mines, referring to the large number of Lake Superior iron mines that used top-slicing, commented in 1930: "Had it not been for the introduction of scraping, it is doubtful whether many underground mines using this system of mining could have been profitably worked during this period [1920 to 1930], when ore prices were low in relation to wage rates."¹²⁵

The author of the WPA's study of iron mining concurred: power scrapers were "the most important technological development in raising

output per man at underground iron mines in the post-war period." "Without the development of mechanical loading underground," the study concluded, "the shift of production to open-pit mines would have been more rapid than it was."¹²⁶ The productivity gains created by the simple tugger-scraper meant that Michigan's underground iron mines would "stay alive" into the 1960s. ■

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Notes:

1. Michigan's mines were overwhelmingly underground. In 1909 only 3 percent of Michigan's iron ore came from open-pit mines. By contrast, that same year 68 percent of Minnesota's production came from open-pit mines. See: A. Hourwich, "Mines & Quarries 1909: General Report and Analysis," *Thirteenth Census of the United States, 1910*, v. 11 (Washington, D.C.: USGPO, 1913), 256. Michigan was the nation's leading iron ore producing state for roughly two decades, 1880-1900. Around 1890 Michigan underground mines produced over 40 percent of American iron ore; the next closest states were Pennsylvania and Alabama at about 10 percent each. See: *Census Bulletin*, no. 113 (24 Sep. 1891): 8.
2. "Address of President William Kelly," *Proceedings of the Lake Superior Mining Institute* (hereafter *PLSMI*) 6 (1900): 15.
3. Stevenson Burke, et al., to W. P. Healy, 12 Mar. 1896, Folder 1, Item 2747, MS 86-100, Cleveland-Cliffs Iron Company Papers, Archives of Michigan, Northern Michigan University repository, Marquette, MI (hereafter MS 86-100, CCI Papers).
4. *Iron Ore* (Ishpeming, MI), 6 Mar. 1897. See also: *ibid.*, 27 Mar. 1897. For additional evidence of the concerns caused by the opening of the Mesabi see: Alfred C. Lane, "The Economic Geology of Michigan in Its Relation to the Business World," *Michigan Miner* 4, no. 1 (1 Dec. 1901): 12, who notes the coming of the Mesabi "caused consternation in the hearts of Michigan ore producers," who "hardly saw where they were coming out"; "A Retrospect of the Mesabi," *Iron Age* 53 (5 Apr. 1894): 658, which notes the alarm on other ranges when the Mesabi opened; "Why Iron Miners Lack Employment," *Chicago Tribune*, 16 Jan. 1894, which attributed high unemployment on other ranges to the Mesabi; and the remarks of Samuel Cooper, a judge on Michigan's Gogebic Range, who noted that when the Mesabi began to ship "we were told that the Gogebic [iron range] might prepare to go out of business" in "The Fifteenth Annual Meeting," *PLSMI* 15 (1910): 29.
5. Shallow open-pit mines, of course, dominated the early history of iron ore production. But by the 1870s the growing demand for iron ore had exhausted near-surface deposits and had compelled producers in many major iron mining regions to resort to shaft mining, as in Michigan's Upper Peninsula, for example. The shift had occurred even earlier in older iron regions like New Jersey and upstate New York.
6. I will focus on the Lake Superior iron ranges because they dominated American iron ore production in the twentieth century. In 1920, for instance, 86 percent of the iron ore mined in the United States came from the Lake Superior district (Michigan, Minnesota, and Wisconsin). See: "Iron-Ore Production in 1920," *Engineering and Mining Journal* [hereafter *EMJ*] 111 (12 Feb. 1921): 302. Michigan was the second leading iron ore producing state, behind Minnesota, throughout the twentieth century. Also, the introduction of slushing (or scraper loading, as it came to be called)—the focus of this essay—was most rapid and "attained its highest state of develop-

- ment" in the Lake Superior iron mines. See: Robert Peele (ed.), *Mining Engineers' Handbook*, 2nd ed. (New York: John Wiley & Sons, 1927), 778; and Sullivan Machinery Co., *Handbook of Scraper Mucking* (Chicago: Sullivan Machinery Co., 1931), 6.
7. N. Yaworski, et al., *Technology, Employment, and Output per Man in Iron Mining* [Report no. E-13] (Philadelphia: Works Progress Administration and Department of the Interior, Bureau of Mines, 1940), 218.
 8. Bureau of Mines publications generally restricted the use of the term "slushing" to systems that used a winch, or tugger, that operated in only one direction (i.e., had manual return), and used a slip scraper, which had a bottom and carried the ore rather than pulled it. The agency used "scraper loading" or "power scraping" for installations using double-drum, reversible hoist engines with power return and bottomless scrapers. However, engineers and managers in the Lake Superior iron district used the terms slusher, scraper-loader, tugger-scraper, and scraper-hoist interchangeably in the 1920s. I follow their practice.
 9. "The Mesaba Range," *Michigan Miner* 4, no. 12 (Nov. 1902): 15, notes that at first it was not practical to use more than 33 percent Mesabi ore in a furnace, but that by 1901 the figure was 45 percent Mesaba, 55 percent old range ores.
 10. William P. Dillingham, *Immigrants in Industries* (pt. 18): *Iron Ore Mining* [61st Congress, 2nd Session, Senate Doc. No. 633] (Washington, D.C.: USGPO, 1911), 211, 390.
 11. R. V. Sawhill, "Confidence Pervades Ore Districts," *Iron Trade Review* 60 (4 Jan. 1917): 85.
 12. On the effect of the war on the region's labor force see, for example: Lucian Eaton, "The Use of Scrapers in Metal Mines," *Compressed Air* 26 (May 1921): 10065; U. S. Congress, *Hearings before the Ways and Means Committee, House of Representatives, on the Proposed Revenue Act of 1918*, pt. I (Washington, D.C.: USGPO, 1918), 917; and "Independent Ore Producers' Case," *Iron Trade Review* 62 (27 June 1918): 1588.
 13. American Mining Congress, *Report of the Proceedings of the American Mining Congress, 24th Annual Convention, Chicago, Illinois, October 17-22, 1921* (Washington, DC: American Mining Congress, 1921), 533.
 14. Cleveland-Cliffs Iron Co. [Hereafter CCI], Mining Department, "Annual Report of General Manager for Year Ending December 31st, 1917," Item 1988, MS 86-100, CCI Papers, 11, 185; *ibid.*, 1918, Item 1989, 755.
 15. Sawhill, "Confidence," 89. See also: Sawhill, "How Ore Districts Meet War Demand," *Iron Trade Review* 62 (3 Jan. 1918): 92; Charles E. Locke, "Mining and Ore Dressing," in Francis G. Wickware (ed.), *The American Year Book 1917*, (New York: D. Appleton & Co., 1918), 471.
 16. "Independent Ore Producers' Case," 1588; U.S. Congress, *Hearings Before the Ways and Means Committee, House of Representatives, on the Proposed Revenue Act of 1918*, pt. 10 (Washington, D.C.: USGPO, 1918), 917; Sawhill "Confidence," 86-7. CCI, Mining Dept., "Annual Report of General Manager, 1918," 755, indicates that the cost of supplies per ton of ore mined rose 22.6 percent from 1917 to 1918 alone.
 17. U.S. Bureau of Corporations, *Report of the Commissioner of Corporations on the Steel Industry* (pt. III), *Cost of Production* (Washington, D.C.: USGPO, 1913), 43. Some years later, Charles Stakel, general manager of Cleveland-Cliffs Iron Company's mining operations, placed the difference in the same ball park, maintaining that for every one cent increase in wages in open-pit mines, underground mines had to absorb an increase of 4.5 cents because underground mines required 4.5 times more labor to produce a ton of ore. ("Stakel Tells of Threats to Mine Industry," *Daily Mining Journal* (Marquette, MI), 10 May 1944.) Iron ore was normally measured by the long ton of 2,240 pounds rather than the short ton of 2,000 pounds.
 18. CCI, Mining Dept., "Annual Report of General Manager, 1917," 29, 92, 165, 172, 183-4, 240.
 19. "American-Boston Mining Co.," report to Frank Webb from J. R. Thompson, 4 Aug. 1917, folder 4, box 1, Hanna Mining Co., Series 2, Iron County Museum [hereafter ICM], Caspian, MI.
 20. CCI, Mining Dept., "Annual Report of General Manager, 1918," 11, 739, 755.
 21. "Michigan Labor Shortage Still Critical," *Automotive Industries* 39 (17 Oct. 1918): 687. See also: "Essential and Non-Essential Employes," *EMJ* 106 (28 Sep. 1918): 578-9, which reported a "great scarcity of miners in the United States."
 22. "Lake Superior Iron Mining Comes to Life," *EMJ* 113 (24 June 1922): 1107; "Michigan: Menominee Range," *ibid.*, 1113 (both on the return of the labor shortage).
 23. M. M. Duncan to William G. Mather, 1 Jan. 1923, in CCI, Mining Dept., "Annual Report of General Manager, 1922," Item 1993, CCI Papers, 15. The company's superintendent in the Gwinn district had reported an exodus of young men to manufacturing plants in Michigan's lower peninsula in 1919 (CCI, Mining Dept., "Annual Report of General Manager, 1919," Item 1990, MS-86-100, CCI Papers, 254). John L. Lovett ("See Need for Many More Laborers," *American Industries* 23 (Feb. 1923): 38) noted that the copper and iron mines of Upper Michigan had been "seriously affected" by the withdrawal of workers who had gone to auto plants.
 24. E. L. Laing to Geo. V. Grieninger, 17 Sep. 1924, folder 33a; E. L. Laing to fee owners of Berkshire Mine, 10 May and 11 June 1923, folder 14; and "Report on the Berkshire Mine for the Month of May, 1922" (7 June

- 1922), folder 11; all in Box 1, Laing/Carey/Dewald Records, Series 3, ICM. See also: "Immigration, a Live Problem," *Iron Trade Review* 70 (29 June 1922): 835; and "Labor Shortage is Increasing," *ibid.*, 1885.
25. *Lake Superior Iron Ores* (Cleveland, OH: Lake Superior Iron Ore Association, 1938), 322.
 26. Numerous authorities point to increasing wage scales and the scarcity of men, especially for mucking, as spurring development and adoption of underground loading devices. Some examples are: M. E. Richards, "Progress in Underground Ore Loading," *PLSMI* 20 (1915): 213, 214; A. M. Gow, "Loading Machines for Underground Use: Their Efficiency in Reducing Mucking Charges," *Scientific American Monthly*, Apr. 1920, 357; "Increasing the Use of Mechanical Devices Underground," *EMJ* 109 (6 Mar. 1920): 590-1; C. Lorimer Colburn, "Underground Loading Devices in Metal Mines," *Mining and Scientific Press*, 124 (28 Jan. 1922): 199; Eaton, "Use of Scrapers in Metal Mines," 10065; and Charles E. Van Barneveld, *Mechanical Underground Loading in Metal Mines* (Rolla, MO: School of Mines and Metallurgy, 1924), 6.
 27. Charles E. Lawrence ("Progress of Mining in Lake Superior District 1894 to 1917," *PLSMI*, 21 (1916-17): 276-9) does not mention the labor-intensive task of mucking as among the techniques that had shifted from hand tools to machinery. Yaworski, et al. (*Technology, Employment, Output*, 151), and Willard E. Hotchkiss, et al., (*Mechanization, Employment, and Output per Man in Bituminous-Coal Mining* [Report no. E-9] (Philadelphia: Works Progress Administration and U. S. Department of the Interior, Bureau of Mines, 1939), 114) note that hand loading was the most labor-intensive underground mining operation. See also: Harold Barger and Sam H. Schurr, *The Mining Industries, 1899-1939: A Study of Output, Employment and Productivity* (1944; reprint, NY: Arno Press, 1972), 97, 189; Richards, "Progress" 213; Ward Royce, "Scraping and Loading in Mines with Small Compressed-Air Hoists-1," *Engineering and Mining Journal* 112 (10 Dec. 1921), 925; and J. H. East, "Scraper Mining Practice," *Alumni Magazine of the Colorado School of Mines*, 13 (Apr. 1924), 8. Van Barneveld (*Mechanical Underground Loading*, 2-4) noted that mucking was the limiting factor in mine production, especially after introduction of the air drill.
 28. Ford E. Boyd, "Slushing Practice in the Mines of the Oliver Iron Mining Company," *PLSMI* 23 (1923): 68; Gow, "Loading Machines" 358. Royce ("Scraping and Loading-I," 925) put the figure at 25 to 50 percent of the time on a shift.
 29. John Ilmari Kolehmainen, *Sow the Golden Seed* (Fitchburg, MA: Raivaaja Pub. Co., 1979), 5. Richards ("Progress," 213) called mucking "the hardest manual labor underground."
 30. For the 1890 strikes see: *Daily Mining Journal*, 5 and 6 Feb. 1890; *Chicago Daily Tribune*, 13 Mar. 1890; and F. P. Mills to William G. Mather, 6 Aug. 1890, Item 2455, MS 86-100, CCI Papers. For the 1892 strikes see: Michigan Bureau of Labor and Industrial Statistics, *Tenth Annual Report of the Bureau of Labor and Industrial Statistics* (1893), 1219; *Iron Ore*, 27 Aug. 1892. For the 1894 strikes see: *Ironwood News Record*, 5 May 1894. For the 1897 strikes see: *Iron Ore*, 18 Sep. 1897; *Daily Mining Journal*, 13, 14, and 27 Sep. 1897; and John P. Beck, "Homegrown," *Michigan History* 79, no. 5 (Sep.-Oct. 1995): 23. For the 1900 strikes see: Michigan Bureau of Labor and Industrial Statistics, *Eighteenth Annual Report* (1901), 243. The Michigan copper district experienced similar problems with trammers, see: Larry D. Lankton, *Hollowed Ground: Copper Mining and Community Building, 1840s-1990s* (Detroit: Wayne State Univ. Pr., 2010), 191-2. For a more detailed account of labor actions on Michigan's iron ranges see: Terry S. Reynolds, "Calm or Conflicted: Labor-Management Relations on the Michigan Iron Ranges, 1855-1904," *Michigan Historical Review* 33, no. 2 (Fall 2007): 1-45.
 31. "Mine Department Agent's Annual Report, Negaunee Mine," 4, in *Agents' Annual Reports and Statistics for Year Ending November 30, 1904*, Item 2077, MS 86-100, CCI Papers. See also: "Labor Shortage Becoming Acute," *Iron Trade Review* 51 (12 Dec. 1912): 1136.
 32. CCI, Mining Dept., "General Manager's Annual Report, 1917," 29, 668.
 33. CCI, Mining Dept., "General Manager's Annual Report, 1919," 21, 213, 234; CCI, Mining Dept., Annual Report of General Manager, 1920, Item 1991, MS 86-100, CCI Papers, 23, 33, 386.
 34. "Increasing the Use of Mechanical Devices Underground," *EMJ* 109 (6 Mar. 1920): 590-1.
 35. Gow, "Loading Machines," 357; Colburn, "Underground Loading Devices," 119.
 36. Royce ("Scraping and Loading-I," 925) mentions the increasing scarcity of "the class of laborers" traditionally recruited for the work of mucking and tramping. See also: Eaton, "Use of Scrapers in Metal Mines," 10074.
 37. What little is known of Anderson's early work with slushing is found in: Van Barneveld, *Mechanical Underground Loading*, 212-3; Eaton, "Use of Scrapers in Metal Mines," 10072; and Boyd, "Slushing Practice, Oliver Mining Co.," 69.
 38. Ulysses B. Hough, "The Kellogg Tunnel," *Mines and Minerals* 22 (Oct. 1901): 122; Van Barneveld, *Mechanical Underground Loading*, 211-2.
 39. E. W. R. Butcher, "Development of Underground Ore Loading: Early Slusher Experiments," *PLSMI* 26

- (1928): 279-80; Richards, "Progress," 215.
40. Colburn, "Underground Loading Devices," 127-8; Eaton, "Use of Scrapers in Metal Mines," 10066; Van Barneveld, *Mechanical Underground Loading*, 210, 213-4, 325.
 41. Van Barneveld, *Mechanical Underground Loading*, 248.
 42. Boyd, "Slushing Practice, Oliver Mining Co.," 68-70; Van Barneveld, *Mechanical Underground Loading*, 213.
 43. Byron G. Best, "The Gogebic Mines of the Oliver Iron Mining Company," *PLSMI* 25 (1926): 99.
 44. Boyd, "Slushing Practice, Oliver Mining Co.," 69.
 45. "Slusher Scraper Success in Underground Iron Mining," *Skilling's Mining Review* 9 (20 Aug. 1920): 7, 11, 14.
 46. Van Barneveld, *Mechanical Underground Loading*, 212-3; Eaton, "Use of Scrapers in Metal Mines," 10072; Boyd, "Slushing Practice, Oliver Mining Co.," 69.
 47. Lucien Eaton, "Use of Scrapers Underground," *Mining and Scientific Press* 123 (19 Nov. 1921): 705; Van Barneveld, *Mechanical Underground Loading*, 248.
 48. CCI, Mining Dept., "Annual Report of General Manager, 1917," 102-3.
 49. Lucien Eaton, "Up-to-Date Practice at Cliffs Shaft Mine-II," *EMJ* 123 (26 Mar. 1927): 519; Lucien Eaton, "Present Scraping Practice at the Cliffs Shaft Mine," *PLSMI* 24 (1925): 121-5; Van Barneveld, *Mechanical Underground Loading*, 222-4.
 50. Van Barneveld, *Mechanical Underground Loading*, 220-1.
 51. Boyd ("Slushing Practice, Oliver Mining Co.," 69) notes that "nearly all" abandoned it after early experiments. Royce ("Scraping and Loading-I," 926) also notes initial resistance to scraping due to the fatiguing nature of the work. Ingersoll-Rand Co., *Modern Methods for Scraper Mucking and Loading* (New York: Ingersoll-Rand Co., 1939), 3, says "many" operators tried slip scraper outfits and abandoned them.
 52. On the contract system in use see: Van Barneveld, *Mechanical Underground Loading*, 216-7; and Royce, "Scraping and Loading in Mines-I," 926.
 53. On miners' skepticism towards operators see, for example: Van Barneveld, *Mechanical Underground Loading*, 5, 13, 213; Boyd, "Slushing Practice, Oliver Mining Co.," 69; and American Mining Congress, *Report of the Proceedings*, 24th Annual Convention, 1921, 536-41.
 54. Gow, "Loading Machines," 357.
 55. "Powerful New Waughoint of Interesting and Novel Design," *Arizona Mining Journal* 5 (1 June 1921): 12; "New Rotary-type Hoist," *Mining and Metallurgy* 2 (June 1921): 39; *The Mining Catalog* 1921 (Pittsburgh: Keystone Consolidated Pub. Co., 1921), 342, 347; "Sullivan 'Turbinair Hoist,'" *Mining and Scientific Press* 123 (2 July 1921): 43-4; Van Barneveld, *Mechanical Underground Loading*, 248.
 56. Best, "Gogebic Mines, Oliver Mining Co.," 99.
 57. "Slusher Scraper Success in Underground Iron Mining," *Skilling's Mining Review* 9 (28 Aug. 1920): 7; "Slushing, The Newest in Underground Technique" [editorial], *Compressed Air Magazine* 36 (May 1921): 10094. See also: Eaton, "Use of Scrapers in Metal Mines," 10065.
 58. Eaton, "Use of Scrapers in Metal Mines," 10065; Eaton, "Use of Scrapers Underground," 703.
 59. D. E. A. Charlton, "Mining in Michigan," *EMJ* 111 (22 Jan. 1921): 164.
 60. "Oliver Iron Mining Co. Will Use Stope Scrapers," *EMJ* 114 (23 Dec. 1922): 1131.
 61. Boyd, "Slushing Practice, Oliver Mining Co.," 77.
 62. Eaton, "Recent Practice in the Use of Scrapers on Sub-Levels," *PLSMI* 22 (1922): 63. See also: George C. Newton, "Drifting with Scraper Slides," *EMJ* 117 (3 May 1924): 731; O. E. Kiessling, et al., "Progress in Mine Mechanization," in: U.S. Bureau of Mines, *Minerals Yearbook, 1937* (Washington, D.C.: US-GPO, 1937), 46.
 63. George J. Young, "Mining Practice," *EMJ* 117 (19 Jan. 1924): 101.
 64. Eaton, "Use of Scrapers in Metal Mines," 10065; Royce, "Scraping and Loading-I," 928.
 65. Van Barneveld, *Mechanical Underground Loading*, 235.
 66. Boyd, "Slushing Practice, Oliver Mining Co.," 77.
 67. Ward Royce, "Scraping and Loading in Mines with Small Compressed-Air Hoists-III," *EMJ* 112 (24 Dec. 1921): 1014, 1016.
 68. Van Barneveld, *Mechanical Underground Loading*, 312.
 69. Eaton, "Use of Scrapers on Sub-Levels," 72-3. Royce ("Scraping and Loading-III," 1016) says that "in practically all the underground operations" where small hoists and scrapers were used, production had been raised "to about double" that of hand shoveling methods. J. A. Noyes ("Slushing Ore with Portable Hoists," *Mine and Quarry* 13, no. 1 (July 1923): 1272) says cost per ton of slushing ore averages half the cost of hand shoveling and tramping, even more under favorable conditions.
 70. Van Barneveld, *Mechanical Underground Loading*, 268, 271, 289.
 71. Van Barneveld, *Mechanical Underground Loading*, 310.
 72. Carroll C. Taylor, "The Gogebic Iron Range," *PLSMI* 25 (1926): 32.
 73. C. H. Funky, "Mining Methods of Castile Mining Company," *PLSMI* 25 (1926): 140-5.
 74. John F. Berteling, "Notes on Mining the North Palms Orebody," *PLSMI* 25 (1926): 56.
 75. D. E. Fritz and L. E. Dick, "Scraping Practice at the Montreal Mine," *PLSMI* 27 (1929): 224.
 76. Lewis, *Elements of Mining*, 337; Sullivan, *Handbook of Scraper Mucking*, 7; L. N. Plein, F. E. Bequist, and F. G. Tryon, *Mechanization Trends in Metal and Non-metal Mining as Indicated by Sales of Underground Loading Equipment* [Report No. E-3] (Philadelphia: Works Progress Administration, 1937), 9.

77. Eaton, "Present Scraping Practice," 121.
78. CCI, Mining Dept., "Annual Report of General Manager, 1923," Item 1994, MS 86-100, CCI Papers, 10-3.
79. CCI, Mining Dept., "Annual Report of General Manager, 1922," Item 1993, MS 86-100, CCI Papers, 72, 74. The Negaunee Mine reported that scrapers were moving 67.6 percent more ore than hand shoveling.
80. CCI, Mining Dept., "Annual Report of General Manager, 1924," Item 1995, MS 86-100, 99; "Annual Report of General Manager, 1925," Item 1996, MS 86-100, CCI Papers, 57, 107, 144, 145. This was a modification of the scraper Eaton had developed for the Holmes Mine. That scraper also found wide use in the underground mines of the Vermilion Range in Minnesota and the Menominee Range in Michigan. Eaton also designed a box-type scraper (bottomless, but with sides) that found use by 1924 in some mines on the Marquette Range, as well as at the Pabst and Anvil-Palms mines on the Gogebic. See: Van Barneveld, *Mechanical Underground Loading*, 220-1.
81. CCI, Mining Dept., "Annual Report of General Manager," material from the reports for the Morris-Lloyd and Barnes-Hecker mines in the period from 1923 to 1927.
82. Van Barneveld, *Mechanical Underground Loading*, 313-4.
83. George C. Newton, "Drifting with Scraper Slides," *EMJ* 117 (3 May 1924): 731.
84. P. N. Ferguson, "The Use of Scrapers," *Technograph* [University of Illinois] 35 (Mar. 1923): 144-5; "Report of Operations—Rogers Mine—Year 1926," Folder 5, Rogers Mine Reports of Operations, Box 5, Hanna Mining Co., Series 2, ICM.
85. Bela Gold, et al., *Technological Progress and Industrial Leadership: The Growth of the U.S. Steel Industry, 1900-1970* (Lexington, MA: Lexington Books, 1984), 295. Van Barneveld (*Mechanical Underground Loading*, 256) says in his 1924 survey that electric scraping hosts were "just beginning to enter the field."
86. Lucian Eaton, *Practical Mine Development and Equipment* (New York: McGraw-Hill, 1934), 165; Robert C. Matson, "Scraping Practice in the Michigan Iron Mines of the Lake Superior District," *PLSMI* 26 (1928): 240, 247.
87. CCI, Mining Dept., "Annual Report of General Manager, 1926," Item 1997, MS 86-100, CCI Papers, 64.
88. CCI, Mining Dept., "Annual Report of General Manager, 1928," Item 1999, MS 86-100, CCI Papers, 140.
89. CCI, Mining Dept., "Annual Report of General Manager, 1929," Item 2000, MS 86-100, CCI Papers, 115, 129, 146, 187, 216.
90. Charles F. Jackson, *Underground Scraping Practice in Metal Mines* [Manuscript Report No. 1, U.S. Bureau of Mines] ([Chicago]: Sullivan Machinery Co., [1933]), 86.
91. East, "Scraper Mining Practice," 8, 10.
92. Eaton, "Recent Practice," 74.
93. Eaton, "Present Scraping Practice," 121. Eaton repeated the statement in CCI, Mining Dept., "Annual Report of General Manager, 1925," 57.
94. Matson, "Scraping Practice in the Michigan Iron Mines," 196, 238. Alabama iron mines were a bit slower than those in Michigan to adopt scraping. (Lucian Eaton, "Mechanical Loading in Metal Mines in 1929," *Mining Congress Journal* 16 (July 1929): 536.)
95. C. F. Jackson, *Some Notes on Underground Transportation: Bureau of Mines* [Information Circular 6326] (Washington, D.C.: USGPO, 1930), 21.
96. Van Barneveld, *Mechanical Underground Loading*, 215, 368; Lewis, *Elements of Mining*, 337; Plein, *Mechanization Trends*, 9; Sullivan, *Handbook of Scraper Mucking*, 6; Austin B. Clayton, "A Study of Mine Scraper Buckets and Their Efficiency" (master's thesis, University of Missouri, Rolla, 1946), 4.
97. The 80 percent figure is calculated from Yaworski, *Technology, Employment, Output*, Table 17 (p. 154), which lists scrapers and shovel-loaders sold to iron mines from 1923 to 1936, and Plein, *Mechanization Trends*, Table 3 (p. 5), which gives the number of scrapers and shovel-loaders sold to all mines in the same period. For the entire period covered by the two sources (1923 to 1936), 75 percent of all scrapers went to iron mines.
98. East, "Scraper Mining Practice," 8.
99. On the necessity of reinventing mine layout see, for example: Gow "Loading Machines," 363; and C. H. Funkey, "Mining Methods of Castile Mining Company," *PLSMI* 25 (1926): 140-1.
100. Best, "Gogebic Mines, Oliver Mining Co.," 102, 107; Matson, "Scraping Practice in Michigan Iron Mines," 263.
101. Jackson, *Underground Scraping Practice*, 13.
102. Roland Parks, "Recent Developments in Methods of Mining in the Michigan Iron Mines," *PLSMI* 26 (1928): 149; Sullivan, *Handbook of Scraper Mucking*, 95; Matson, "Scraping Practice in Michigan Iron Mines," 265.
103. For example: CCI, Mining Dept., "Annual Report of General Manager, 1925," 179. See also: Eaton, "Use of Scrapers in Metal Mines," 10072, 10074.
104. Royce, "Scraping and Loading-I," 928; Ward Royce "Scraping and Loading in Mines with Small Compressed-Air Hoists-III," *EMJ* 112 (24 Dec. 1921): 1016; Gow, "Loading Machines," 363; Van Barneveld, *Mechanical Underground Loading*, 74-5, 79-89, 112, 115, 119; Eaton, "Up-to-Date Practice," 50.
105. "Morris-Lloyd Mine of North Lake," *Iron Ore*, 19 June 1915; "Savings Due to Underground Car Loader," *EMJ* 101 (22 Jan. 1916): 184; Richards, "Progress," 214-5.
106. Van Barneveld, *Mechanical Underground Loading*, 20-1. For his detailed descriptions of the various

- models see 134-209. See also: Richards, "Progress," 213-21, and Colburn, "Underground Loading Devices," 119-26.
107. Yaworski, *Technology, Employment, Output*, 152.
 108. P. E. Barbour, "General Review of Mining in the United States in 1915," *EMJ* 101 (8 Jan. 1916): 108; "New Trade Publications," *Iron Trade Review* 58 (17 Feb. 1916), 409.
 109. Van Barneveld, *Mechanical Underground Loading*, 173, 177.
 110. Colburn, "Underground Loading Devices," 126.
 111. CCI, Mining Dept., "Annual Report of General Manager, 1919," 94, 234.
 112. "Present Status of the Underground Loader," *Skillings Mining Review* 8 (15 Nov. 1919): 3.
 113. George R. Jackson, "The Mayne Loader," *PLSMI* 22 (1922): 143-52; *Iron Ore*, 27 Jan. 1923; Van Barneveld, *Mechanical Underground Loading*, 278-88.
 114. Ferguson, "Use of Scrapers," 144.
 115. "Oliver Will Use Stope Scrapers," 1131.
 116. Matson, "Scraping Practice in Michigan Iron Mines," 254.
 117. Gow, "Loading Machines," 363. See also: Eaton, *Practical Mine Development*, 149.
 118. Van Barneveld, *Mechanical Underground Loading*, 113. See also: Sullivan, *Handbook of Scraper Mucking*, 14.
 119. Eaton, "Use of Scrapers in Metal Mines," 10074.
 120. Van Barneveld, *Mechanical Underground Loading*, 13-5.
 121. Discussion of the comparative advantages and disadvantages of the tugger-scraper (or scraper-loader) and shovel-loader are numerous. Some of the better are: Eaton, "Use of Scrapers in Metal Mines," 10074; Van Barneveld, *Mechanical Underground Loading*, 388; and A. C. Stoddard, "Mechanical Mucking Underground vs. Slushing," *Skillings Mining Review* 25 (31 Oct. 1936): 1-2, 7.
 122. William Hawes ("A Monument Should Be Build Honoring These Guys: The Invention of the Mucking Machine," *Mining History Journal* 20 (2013): 30-9) provides an account of the invention of this machine.
 123. British engineers Douglas Hay and N E. Webster ("Scraper-Loading," *Transaction of the Institution of Mining Engineers* 79 (1929-30): 64, 75-6) attribute the origin of the practice to the United States. Early reports of scraper use in other countries also suggest American origins, for example in Peru (C. S. T. Farish and J. C. Pratt, "Scraper Loaders, as Designed and Used at Casapalca, Peru," *EMJ* 123 (16 Apr. 1927): 636) and in South Africa (G. A. Watermeyer and S. N. Hoffenberg, *Witwatersrand Mining Practice* (Johannesburg: Transvaal Chamber of Mines, Gold Producers' Committee, 1932), 348).
 124. Yaworski, *Technology, Employment, Output*, 210, 221 [Table A-4 (Michigan employment data), and Table A-6 (Michigan-Wisconsin tons per man-hour data)].
 125. Jackson, "Underground Scraping Practice," 66.
 126. Yaworski, *Technology, Employment, Output*, 134, 151, 159.