"The Miners Dread to Use It": A Comparative Study of the Introduction of Nitroglycerin on the Lake Superior Copper and Iron Ranges, 1865-1880

By Terry S. Reynolds

> *"The miners dread to use it [nitroglycerin] from . . . a fear of its tremendous power, and are against its general introduction for the reason that it will materially revolutionize and change the present system of mining."—Jacob Houghton,* Lake Superior Miner *(Ontonagon, Michigan), 21 April 1869.*

On Saturday morning, 5 February 1870, the day shift entered the workings of the Washington mine on the Marquette Iron Range, about twenty-five miles inland from the southern shore of Lake Superior on Michigan's Upper Peninsula. They began to drill the holes in iron-bearing rock into which a relatively new explosive—nitroglycerin oil—would be placed and detonated. They did not know that one of the blast holes drilled by the night shift had not detonated and still contained nitroglycerin oil. The night shift's contract blaster had either failed to notice that one of the holes he had charged had not detonated or he had not reported that fact to the day shift's blaster.

At around 11 o'clock one of the day shift's Cornish crews placed a drill in that hole and struck it with a sledge hammer. The glycerin oil exploded, fracturing the skull of one member of the crew and seriously injuring the back of a second. The third, probably the miner holding the drill, was even less fortunate. He had a badly burned left eye, a broken left arm, and a mangled left hand that required amputation.

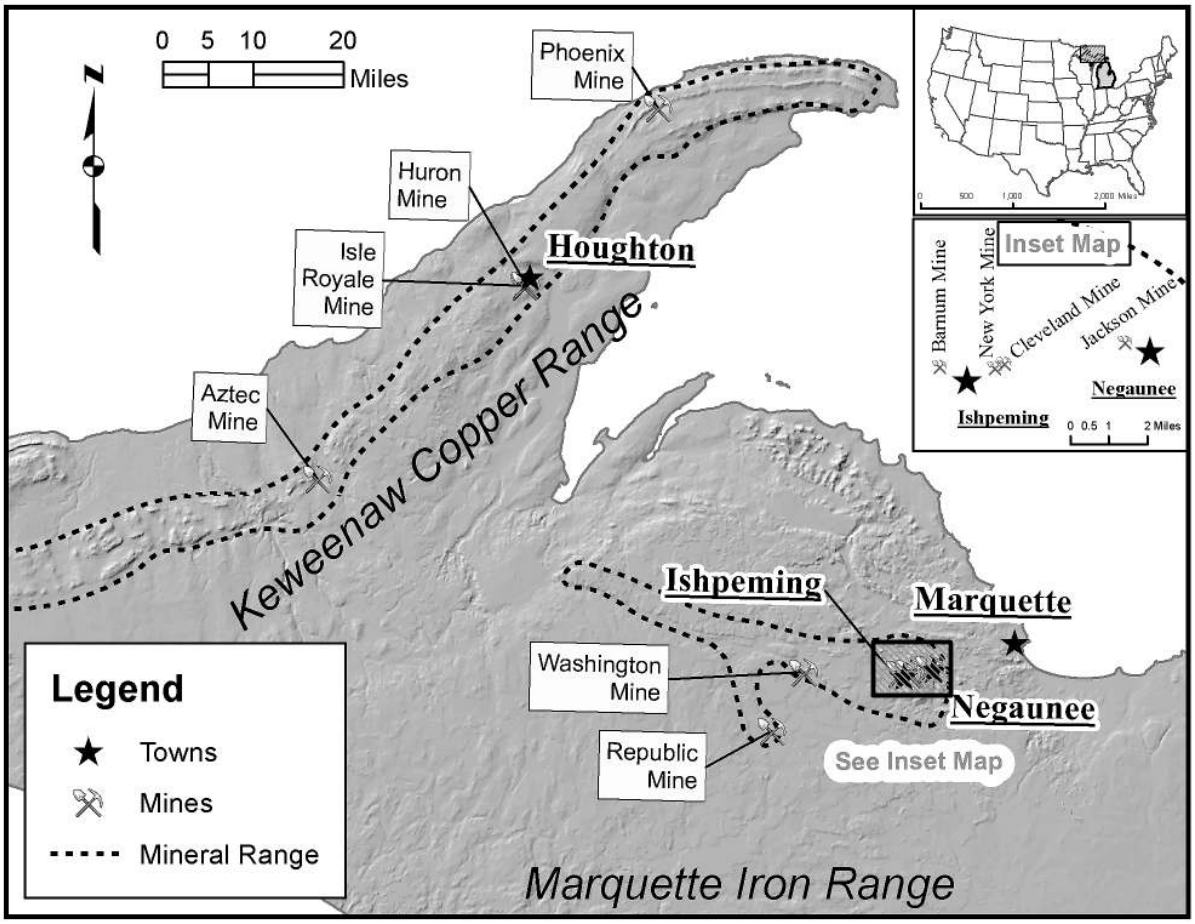
The three hundred miners working at the site immediately walked off the job and threatened the mine's officers. The officers panicked and

telegraphed the local sheriff for protection. Arriving as quickly as he could from the county seat at Marquette, twenty-five miles away, the sheriff calmed matters. On Sunday things were quiet, but on Monday the Washington's miners struck to prevent further use of nitroglycerin and told the mine's manager that he had until 9 a.m. the following morning to "leave the place."

On Thursday, 10 February, strikers attacked George A. St. Clair, the blasting contractor, with rocks. St. Clair drew a revolver and fired, ending the attack. Later that week, a group of miners decided to "get even" with Dan Northy, the man who handled the nitroglycerin for St. Clair. They marched as a unit to Northy's office, only to have Northy meet them at the door with a fused can of nitroglycerin in one hand and a match in the other. The strikers hurriedly dispersed, falling over each other to get away.

The strike continued for more than two weeks, ending when John H. Mitchell, a spokesman for the miners, absconded with several thousand dollars collected from regional miners to support the strike. The Washington's miners slowly trickled back to work.[1] A month or so later, miners at the nearby Champion mine created a mutual benefit society to aid injured members or the widows and orphans of those killed. They prohibited anyone working with nitroglycerin from joining the organization.[2]

The small village of Houghton, near the geographic center of Upper Michigan's Keweenaw Copper Range, lies fifty to sixty miles northwest of the Washington mine. Around one o'clock on



The Lake Superior copper and iron ranges circa 1870. The Marquette Range was the only producing Lake Superior iron range in 1870; by 1914 five others would in production. (Map by Timothy Goddard.)

the morning of Tuesday, 17 April 1870, about two months after the Washington mine strike, an explosion like "a sharp, ripping clap of thunder" awakened Houghton's residents. Some still awake at that hour reported that the "electric flash" that accompanied the explosion illuminated the night sky.

The next day the town's inhabitants learned the cause. Disenchanted copper miners had detonated a storage shack near the Huron copper mine that contained a can holding fifty-seven pounds of liquid nitroglycerin, a keg of powder, and miscellaneous mining paraphernalia. These materials belonged to the Mabbs brothers, the Huron mine's new nitroglycerin blasting contractors. "Scarce a vestige of the shanty was left," the local paper reported. Candles, fuse, and other mining supplies stored in the shed littered an acre surrounding the site.

This incident culminated a week-long strike by the Huron's miners against the introduction of liquid nitroglycerin. The strike had included mass meetings, intimidation of Mabbs brothers' employees, and a threat to ride the blasting contractors out of town on a rail. The day after the explosion the Huron mine's agent caved in, canceling the blasters' contract and asking them to remove any remaining blasting oil from the mine's property. Meanwhile search parties made up of miners searched in vain for the Mabbs brothers' remaining supplies of nitroglycerin, by now well hidden, with the intention of destroying them.[3]

Early experimentation with nitroglycerin blasting oil in the Lake Superior copper and iron mining districts is not surprising, despite their geographical isolation from the flow of American settlement and its population centers. From its introduction in the mid-1860s, nitroglycerin's potential to radically transform mining had been quickly understood. Indeed, the so-called "high explosives," of which nitroglycerin oil was the first, eventually revolutionized mineral production, having an influence on the industry comparable only to the introductions of steam power and compressed air drills.[4]

Thus, promoters of the new blasting compound quite naturally targeted the relatively recently opened Lake Superior copper and iron ranges, seeing them as potentially important markets. By 1870 the Keweenaw Copper Range on Lake Superior was America's leading producer of the red metal. By that same date the Marquette Iron Range was on its way to becoming the most important American iron mining district, already producing around 20 percent of the nation's iron ore and shipping it to dozens of blast furnaces in and around Pittsburgh, Youngstown, and Cleveland.

The introduction of nitroglycerin onto the Lake Superior copper and iron ranges offers a nice study in parallels and contrasts, and provides insights into the factors that affect the reception of new technologies in different environments. Early on the two ranges followed parallel paths.

Basically, in 1866 and 1867 agents hoping to create a market for the new explosive persuaded a mine or two in both regions to use trial samples. Convinced of its potential, in 1868 and 1869 some mining officials purchased quantities of the new compound, and some blasting and handling accidents occurred. In 1869 agents of nitroglycerin manufacturers began to push more aggressively for the adoption of blasting oil, agreeing to contract or sub-contract blasting themselves, since miners were reluctant to handle the substance. And, as we have seen, in 1870, within three months of each other, miners on both ranges struck over the use of nitroglycerin oil.

After early 1870, however, Michigan's copper and iron ranges took divergent paths. Nitroglycerin found widespread acceptance on the Marquette Iron Range. So widely was the new explosive used on the iron range that by 1872 two nitroglycerin companies had erected plants locally to supply the growing demand. Even a massive nitroglycerin accident in 1878, which killed seven and damaged buildings all over the mining town of Negaunee, provoked no serious reaction.[5]

On the Keweenaw Copper Range, however, miners, mine captains, mine agents, and local newspapers rejected the explosive. Mining companies in the copper district would not begin to use high explosives regularly until almost a decade later, between 1878 and 1880, and then only in the safer form of dynamite or some other solid modification of nitroglycerin.

Only a small literature deals with the introduction of high explosives in American mining, and little has been done on the issue of why some regions embraced the innovation while others resisted. This essay represents an initial probe in that direction. What it suggests is that the diffusion of a technological innovation like nitroglycerin oil is a complex process that depends on a complex of interrelated geological, technological, and social factors.

The Emergence of High Explosives

In the mid-1840s, Ascanio Sobrero, an Italian chemist, discovered that he could produce a powerful explosive by reacting glycerin, a byproduct of soap manufacturing, with nitric acid in the presence of sulfuric acid. The resulting compound—a relatively clear, oily liquid called nitroglycerin—had some minor medical applications, but was extremely difficult to detonate. The compound thus remained largely a scientific curiosity until the early 1860s, when Alfred Nobel in Sweden conceived of using it as a blasting agent in mines and for road and railroad construction. Working with his father and a brother, he developed methods for producing the chemical in quantity and patented several means of igniting the substance using gunpowder and, later, mercury fulminate as detonators.

Tests indicated that the new explosive was significantly more powerful than traditional black powder. The strength of a nitroglycerin explosion had additional benefits. Miners did not have to bore blast holes as deep or bore as many holes, reducing drilling expenses. And because nitroglycerin exploded far more rapidly than gunpowder, it shattered rock more completely. This meant that those involved in blasting had fewer large pieces of blasted-down rock to re-blast or break up with sledge hammers. The new blasting oil thus offered considerable potential savings in time and in labor, the leading cost in mining and railroad construction. As an extra bonus it could be used in wet conditions where conventional blasting powder could not.[6]

Following the death of his brother in an explosion at the family's nitroglycerin factory near Stockholm in 1863 and his father's withdrawal from the business due to that accident, Alfred Nobel became the leading promoter of the new compound.[7] At first, Nobel regarded nitroglycerin, or blasting oil, both as a more powerful alternative to traditional blasting power and as a safer one.

After all, unlike traditional blasting power, nitroglycerin oil did not ignite from incidental spark or fire, the usual cause of accidents with black powder. Also, it was much more likely to be completely consumed when ignition did occur, reducing post-explosion accidents. With its seeming advantages in power, reduced labor costs, and safety, Nobel's blasting oil found early application in mines, quarries, and road and railroad construction projects in parts of western Europe.

The explosion that destroyed the family's nitroglycerin factory near Stockholm and killed Alfred Nobel's brother led to Swedish restrictions, so Nobel erected a plant near Hamburg and began to seek broader markets. In July 1865 an American with loose ties to one of Nobel's German partners demonstrated blasting oil on a cliff on the lower Palisades near New York City, marking its American debut.[8]

In early 1866 the Central Pacific Railroad, then encountering problems in blasting tunnels and cuts in the hard rock of the Sierra Nevada, sought trial samples.[9] Agents had the oil transported from Nobel's factory in Germany to England, then shipped to the Isthmus of Panama, carried across the Isthmus, reloaded on vessels and

carried to San Francisco, where another of Nobel's partners had formed an agency to market the explosive.

But on 3 April 1866, a vessel carrying seventy cases of liquid nitroglycerin exploded at Aspinwall (Colon) on the Caribbean side of the Isthmus, destroying the vessel, the wharf to which she was tied and nearby warehouses, and killing sixty. Two weeks later part of another shipment that had successfully reached San Francisco exploded at a Wells Fargo and Company Office, destroying the structure and killing fifteen.[10] Another accident near a trial blast site on the Central Pacific killed six.

These and other transportation and handling accidents soon convinced Nobel that his blasting oil was not as safe as he had initially thought. It was highly sensitive to detonation if subjected to high temperatures, such as in the hold of a ship in the tropics, or if not manufactured to the highest standards of purity. Both high temperatures and excess acid or impure glycerin produced blasting oil that deteriorated quickly and exploded when subject to sudden shock in a confined space. The spectacular and widely reported glycerin explosions at Aspenwall and San Francisco, as well as other incidents, quickly gave the new explosive a bad reputation. Britain's Parliament and America's Congress soon restricted its transportation on public conveyances.

As problems with liquid nitroglycerin emerged, particularly difficulties in safely transporting and handling the substance, Nobel responded in two ways. First, he recognized that long-distance transportation had become out of the question; shipping companies were unwilling to accept the compound. Manufacturing facilities would have to be erected in multiple locations instead of being concentrated in Germany. To this end he visited the United States in July 1866, with the intention of interesting Americans in the compound and forming a company—eventually, the United States Blasting Oil Company—to manufacture nitroglycerin under his patents in the United States or license others to do so.

Nobel's other response was to seek a means to reduce the dangers inherent in liquid nitroglycerin. He found that if nitroglycerin oil were absorbed by an inert material, like fuller's earth, it formed a clay-like substance that stored and aged better and was much harder to detonate—even when subjected to shocks—than nitroglycerin oil. Wrapped in a waterproof paper or cardboard cylinder and provided with a fuse and a means of detonation (such as mercury fulminate) only after arriving at the blast site, the resulting product could be safely shipped and stored for long periods before use. In 1867 and 1868 Nobel patented his new product, called dynamite or "giant powder." While less powerful and more expensive than his original blasting oil, Nobel's new product had advantages in safety and ease of handling sufficient for it to quickly find a market.[11]

Nobel was unable to monopolize production of "high explosives," however, since he had not discovered nitroglycerin, simply a means of economically manufacturing and efficiently detonating it. Imitation was relatively easy. The reactions that produced nitroglycerin were not complex. The equipment was not costly; a small shed could house it. Rivals soon developed their own processes for manufacturing and detonating.

Nobel's leading rival in the United States was George Mowbray. By December 1866, Mowbray had begun production of nitroglycerin oil, claiming that his manufacturing process produced a purer product less prone to accidental explosion or decomposition in storage than Nobel's. Mowbray secured the contract to do blasting on the Hoosac Tunnel in western Massachusetts in early 1867, constructing a small factory on site to produce nitroglycerin and avoid the issues of long-distance transportation. He also discovered that he could transport nitroglycerin more safely by freezing it, something made relatively easy by its high freezing point of around fifty-five degrees Fahrenheit.[12] Nobel would even have trouble protecting his dynamite patents. Imitators tried to evade them by

using absorbents for nitroglycerin oil different from Nobel's, including sawdust, rotted wood, salt, and gunpowder.[13]

Nobel's agents, and imitators like Mowbray, very quickly identified obvious markets for their products. Probably the first extensive use of blasting oil in the United States occurred on the Central Pacific Railroad, then making very slow progress using conventional blasting powder in its summit tunnel in the Sierra Nevada, and on the Union Pacific, coming from the east and facing similar problems in the Rockies. Both erected nitroglycerin manufacturing facilities near their tunneling operations in 1867 to reduce legal, transportation, and handling problems.[14]

George Mowbray, the most successful of Nobel's early imitators in the United States, entered the business in 1866. After developing improved methods for manufacturing nitroglycerin, he won the contract to provide basting oil to the Hoosac Tunnel project in western Massachusetts. Agents of a company he licensed were the most aggressive in introducing nitroglycerin blasting oil on the Lake Superior mineral ranges. (From: George M. Mowbray, Tri-Nitro-Glycerin as applied in the Hoosac Tunnel, Submarine Blasting, Etc. *(North Adams, MA: James T. Robinson and Son, 1872), frontispiece.)*

Introducing Nitroglycerin on the Lake Superior Copper and Iron Ranges

Like the transcontinental railroad, the rapidly expanding copper and iron ranges of Upper Michigan were obvious markets for manufacturers of blasting oil. In early 1866 Otto Burstenbinder—a get-rich-quick schemer who had ties to Nobel's German partner, but who acted without Nobel's authority or knowledge—brought samples of blasting oil to the Marquette Iron Range.[15] In March 1866 the superintendents of several mines had Burstenbinder demonstrate the product. They were impressed. F. P. Mills of the Cleveland mine, adjacent to what would soon become the village of Ishpeming, reported its explosive power "manifold greater than powder." Henry Merry of the nearby Jackson mine called a single blast with three pounds of oil contained in a tin cartridge "simply astonishing," and estimated that it would have required four to six shots with conventional blasting powder.[16]

Although Burstenbinder had no blasting oil to sell, and legal restrictions on transporting it due to nitroglycerin accidents had begun to make long-distance supply difficult, his trial samples had performed well enough to create interest on the iron range. In December 1867 Edward Breitung, an officer of the Washington mine, announced that he would bring nitroglycerin to the mine over the snow to give it a further trial.[17]

In 1869 Jacob Houghton, an agent representing the Mowbray-licensed Lake Shore Nitro-

glycerin Company, of Painesville, Ohio, began systematically working both the iron and copper regions of Michigan. Younger brother of Douglass Houghton—Michigan's first state geologist, whose geological work had set off the copper rush to Michigan's Upper Peninsula in the mid-1840s—Jacob Houghton had worked on government land and geological survey parties on the Upper Peninsula, including the party that, in 1844, had first discovered iron specimens near what would become the Jackson mine. Later he worked as a surveyor for several railroads and as a superintendent and agent for several Lake Superior mines.[18]

In August 1869 Houghton placed an ad announcing the availability of nitroglycerin blasting oil and published articles on its advantages in the region's leading newspapers.[19] By the end of the month, the yacht *Myra* delivered 2.5 tons of Mowbray-licensed blasting oil from Lake Shore's factory in northern Ohio to Jacob Houghton at Marquette, the port serving the iron range.[20] Over the next few months, Houghton exhibited the product to regional mine managers and gave a public demonstration on the waterfront at Marquette.[21] Before the year was out he had secured contracts to do all of the blasting for three mines in which nitroglycerin had been demonstrated by Burstenbinder in 1866—the Jackson, the Washington, and the Cleveland.[22]

Chronologically, the introduction of blasting oil on the Keweenaw Copper Range roughly paralleled its introduction on the Marquette Iron Range. In the summer of 1867 the *American Journal of Mining* reported that the Phoenix mine, on the northern end of the range, was experimenting with nitroglycerin. These trials were apparently so successful that by December the company had stockpiled twenty tons of the explosive for winter work. The company's annual report for 1867 boasted that the new explosive would revolutionize mining, and that its mine was the only one that had the material or was likely to be able to get any for some months to come.[23]

Once the ice on Lake Superior melted the following spring, however, other copper mines began to import blasting oil. In 1868 and 1869 scattered reports indicate that nitroglycerin had been introduced at the Copper Falls mine in the northern part of the mining district, the Aztec mine in the southern part of the district, and at the Isle Royale mine, near the village of Houghton, in the central part of the district.[24]

Early reports from both the copper and iron ranges suggested general satisfaction. The Phoenix Copper Company's 1867 annual report claimed that with the new blasting oil miners could drive drifts fifty feet per week; before they could only make twenty-five or thirty feet per month.[25] The *Lake Superior Miner* reported in August 1869 that, at the Aztec, fifteen men with nitroglycerin could do the work of twenty-five with traditional blasting powder.[26] Things seemed to be going equally well on the Marquette Iron Range. In early 1870 the New York mine, adjacent to the Cleveland, joined that mine, the Jackson, and the Washington in contracting with Jacob Houghton to do blasting with nitroglycerin, and managers at the Washington mine reported that work with nitroglycerin was going well.[27]

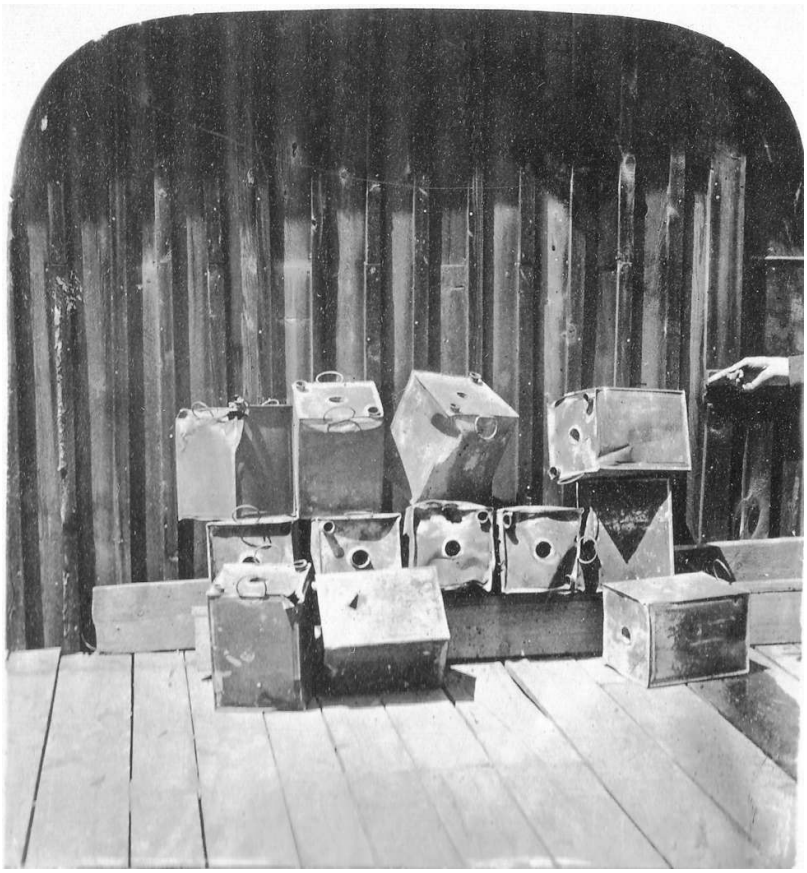
Much of the early success may have resulted from how mine agents eased the compound, with its bad reputation, into the mines. Traditionally in the hard rock mines of Lake Superior, three-man teams of skilled miners drilled blast holes by hand, charged them with powder, and carried out a blast at the end of each shift. To moderate resistance to nitroglycerin, mine superintendents on both the copper and iron ranges separated the drilling and blasting functions in one of two ways.

In some cases, mine agents contracted blasting to representatives of the nitroglycerin manufacturers. These contractors would come in at the end of every shift, charge the holes miners had drilled, and carry out the blast. In other cases, the companies had representatives of the nitroglycerin companies train several workers on each shift to safely handle blasting oil. These designated

blasters came on site to charge and blast after the miners left at the end of each shift.[28]

But even as these techniques eased the transition to nitroglycerin, and even as favorable reports appeared in regional newspapers, disquieting signs emerged on both ranges. On the copper range, the Phoenix, the first user of the explosive, suffered at least two serious nitroglycerin accidents in 1868. Information is sketchy, but early in the year a nitroglycerin accident blew up one of the company's change houses; later an explosion killed one of the mine's specially trained blasters.[29] When management introduced blasting oil at the Aztec a number of miners quit and hired on at other mines.[30] The *American Journal of Mining* reported in June 1868 that miners at Copper Falls, in the northern part of the copper range, had been "spooked" by the introduction of nitroglycerin.[31] Because of blasting oil's bad reputation, the village of Houghton refused to allow a vessel carrying the product to land at its docks in August 1869, compelling her to tie up at the docks of the Isle Royale Company roughly half a mile from the village.[32] Later that month an anonymous poet published verse in the *Portage Lake Mining Gazette* suggesting that those who authorized use of the oil, rather than miners, should carry out the detonations. In the fall of 1869 miners at the Isle Royale copper mine attempted to prevent its introduction.[33]

To the southeast, on the iron range, unknown parties attempted to break into the nitroglycerin magazine near the Jackson mine in January 1870, and the Marquette newspaper noted that the region's Cornish miners did not like the new blasting "ile."[34] The growing concern over blasting oil, punctuated by occasional accidents with the material, culminated in the strikes which introduced this essay: at the Washington mine on the Mar-



Liquid nitroglycerin was frequently transported in paraffin-lined square tin containers like these. Typically, each held about forty pounds of the liquid. (From: Mowbray, Tri-Nitro-Glycerin*, facing p. 18.)*

quette Iron Range in February 1870 and at the Huron mine on the Keweenaw Copper Range in April 1870.[35]

Use of Nitroglycerin Oil on the Lake Superior Copper and Iron Ranges after 1870

Although the early use of nitroglycerin had followed a parallel course on the two mining ranges, after the spring of 1870 their responses to the use of liquid nitroglycerin diverged sharply. Marquette Iron Range mines increasingly embraced the new explosive, to the point that its use had become general by the early 1870s. Keweenaw Copper Range mines, however, turned away from glycerin, using traditional black powder almost universally until the very late 1870s.

Most scholars who have studied the Keweenaw have seen the Huron strike as the turning point in the use of nitroglycerin. Gates noted that after the Huron strike "anything bearing the name 'nitroglycerin' or 'dynamite' became an anathema to Lake miners." Lankton and Hyde, in multiple publications, concurred, observing that the region's copper mines mostly did not begin to adopt high explosives until the late 1870s, when they began to experiment with dynamite or similar products.[36] After the Huron strike, the Mabbs brothers transferred their remaining supply of nitroglycerin to the Marquette Range.[37]

In late 1872 or early 1873 the *Portage Lake Mining Gazette* asserted that regional copper mines used only black powder.[39] The only exception seems to have been the Phoenix mine, the pioneer user of nitroglycerin in the copper district. In 1874 it was using dualin, a nitroglycerin-based product similar to dynamite and generally considered safer than nitroglycerin oil. But a massive explosion in February killed six, threw body parts up to 250 yards, and ended that experiment.[38] Thomas Egleston of the Columbia School of Mines, visiting the region in 1876, reported that the region's copper mines used black powder "exclusively" in blasting, and that the miners disliked nitroglycerin, dynamite or any other modern explosive because the air after a blast gave them headaches.[40]

On the iron range, however, things went very differently. The failure of the strike at the Washington mine meant that by March 1870 at least four of the region's fourteen shipping mines—the Washington, the Jackson, and two of the Jackson's neighbors, the New York and the Cleveland—were using nitroglycerin regularly. That same month Jacob Houghton reported that he had sold out his supply of blasting oil and would be going down lake for more.[41]

Despite several accidents using nitroglycerin at local mines, use of the explosive continued to increase. In June 1870 Marquette's *Mining Journal* claimed that miners had adjusted to the new explosive and actually liked using it. That same month the Edwards mine near the Washington, and the New England mine near Negaunee, decided to give nitroglycerin a trial. The Barnum mine at Ishpeming adopted it a few months later.[42] Thomas Brooks, a former mine manager and regional mining consultant, reported over seventy thousand dollars worth of nitroglycerin sold in the Marquette region in 1870.[43] Frank P. Mills, the tough mining superintendent of the Cleveland mine, who had once been "much opposed" to the introduction of nitroglycerin, declared in late 1870 that "he would not like to have to work without it."[44]

In June 1870 the editor of the *Mining Journal*, contrasting the iron district which it served to the copper district, commented that the "same prejudices [against blasting oil] don't exist here."[45] When the Barnum mine decided that August to use nitroglycerin, the *Negaunee Mining Review*, another iron range newspaper, declared that the prejudice against nitroglycerin oil was "rapidly dying out."[46]

How quickly this happened on the iron range may be illustrated by an incident at the Republic mine in 1873. In early March a nitroglycerin explosion killed the mine's blaster. Within twenty-

four hours a half dozen men had applied for the vacant position, so "accustomed to the use of nitroglycerine" had regional iron miners become.[47] The *Mining Journal* reported in January 1871 that blasting oil was in use "in nearly all the hard ore mines" of the district and was "rapidly growing in favor."[48] Surviving records indicate that the Washington mine used more blasting oil than blasting powder in 1874.[49] *Iron Age* reported in 1874 that nitroglycerin oil was "in constant demand" on the iron range.[50]

Blasting oil did not completely supersede traditional black power, of course. For breaking soft ground and for other conditions warranting a more controlled explosion, such as in the region's relatively new soft-hematite mines, black power remained in use. However, when students from the Columbia University School of Mines visited Marquette Range mines in 1881, they found the use of high explosives "almost universal," although by that time many of these were dynamites.[51]

Indicitive of the rapidly expanding use of nitroglycerin on the Marquette iron range, in late 1870 the Lake Shore Nitroglycerine Company decided to move its manufacturing facilities from northern Ohio to Marquette.[52] A short time later, the company moved a dozen miles inland to be closer to the mines it served and to reduce its transportation problems. In 1871 a second nitroglycerin company formed to serve the area, and not long after that several other smaller nitroglycerin manufacturing operations emerged.[53] A Washington Iron Company inventory from 1875 lists a "Nitro Glycerine Factory," and several other sources mention nitroglycerin production at Humboldt, the settlement closest to the Washington mine.[54]

In 1876, at a time when probably no Lake Superior copper mine was using any nitroglycerin, the Marquette iron range had at least three operating factories producing the blasting agent, and the manager of the Lake Shore Nitroglycerin Company, C. M. Wheeler, reported that his works were as busy as any comparable works in the entire country.[55] In 1877 yet another firm—The Miner's Powder Company—started producing the substance near Negaunee.[56]

Factors Influencing the Dissimilar Receptions of Nitroglycerin Oil

How are we to account for the decade's difference between when Lake Superior iron mines adopted nitroglycerin in about 1870, and when the region's copper mines belatedly did so around 1880? No contemporary source discusses the issue, but one possible explanation—that mine owners on the iron range were simply more innovative generally than mine owners on the copper range—certainly does not hold water. Mines on the copper range introduced steam power for hoisting and pumping well before those on the iron range, and both ranges experimented with and eventually adopted pneumatic rock drills at roughly the same time.

The dissimilar geology of the two regions offers one clue to the question. The primary ore mined on the Marquette Iron Range in 1870 was a black, hard, crystallized iron ore, sometimes referred to as specular hematite, although some mines like the Washington were extracting magnetite. To reach the hematite ore, miners on the Marquette Range often had to drill through quartzite and an even tougher rock, a low grade iron formation called jasper, or jaspilite, which intruded into and sometimes mixed with the desired ore.

John W. Foster, who carried out early geological exploration in the region, reported in 1865 that a three-man hand-drilling team working an eleven hour shift sometimes could penetrate only one foot into the jaspery hematite of the region's hard ore mines, whereas eight feet a day was the regional average when drilling into the hematite ore itself.[57] A. P. Swineford, a local mining journalist and later Michigan's commissioner of mineral statistics, reported that drilling a hole one foot deep at several of the pits of the Cleveland

hard ore mine could dull five hundred to six hundred drill steels.[58] The Cleveland mine had notoriously hard rock, and Swineford's example must have been unusual, for another writer reported that only sixty or seventy steels were dulled cutting a hole three feet deep in the same company's works.[59]

The basalts of the copper range were also tough rock to drill. Thomas Egleston of the Columbia University School of Mines indicated in the late 1870s that three men working a shift could "easily" drill three holes 2.0 to 2.5 feet deep, or 6 to 7.5 feet in total, into moderately hard rock, a figure comparable to Foster's for the iron range.[60] But an 1870 article indicates that a 2.5- to 3-foot deep drill hole in copper-bearing rock dulled only forty steels, suggesting that drilling copper rock may have been a bit easier than drilling iron rock.[61]

Evaluating the comparative difficulty and expense of drilling and blasting rock on the two ranges around 1870 is extremely complicated, since rock hardness, texture, abrasiveness, fracture pattern, and other characteristics of the rock formations would all have to be taken into account, and they differed enormously from location to location. This was especially the case on the Marquette Iron Range, where rock formations were much more folded than on the copper range. While exact comparative data do not exist, the rock of the Negaunee iron formation on the Marquette Range is certainly more difficult to drill than the basalts and conglomerates of the copper region.[62] But by itself, difficulty drilling is insufficient to explain the differential response to nitroglycerin. The Calumet and Hecla mine had the hardest rock in the copper region, yet it was not among the first to try or to adopt nitroglycerin.

Other factors contributed to the differential response on the two ranges. A primary one was the timing of the introduction of nitroglycerin. By 1870 all of the Lake Superior copper mines were underground operations, while most of the iron mines on the Marquette Range were still either entirely or mostly open pit or quarry operations. In open pit operations, or even adit operations like the Washington mine, some of the objectionable elements of nitroglycerin's use would have been less significant.

The noxious fumes that miners complained gave them headaches after a nitroglycerin blast were a serious factor underground, where ventilation was often poor and the air was only slowly cleared after blasting. These fumes would have been much less of an issue in open air mines.[63] The significantly greater magnitude of nitroglycerin explosions and the lesser familiarity with that explosive were probably less worrisome in open air operations than underground, where miners had to worry about the roof coming in. The handling of touchy explosives was also easier above ground than below, due to fewer impediments in handling and better light. Sunlight was certainly better than candlelight when dealing with blasting oil.

Nitroglycerin was also somewhat easier to apply in the vertical bore holes common in open pit operations than in the horizontal or downward-slanting holes common in overhand-stope copper mines, though this was only a minor concern. Generally blasters loaded drill holes with liquid nitroglycerin contained in stoppered metal, rubber, or wooden tubes, called cartridges. This was often the case even in the vertical bore holes of open pit mines, since miners quickly discovered that blasting oil used without cartridges would drain into cracks.

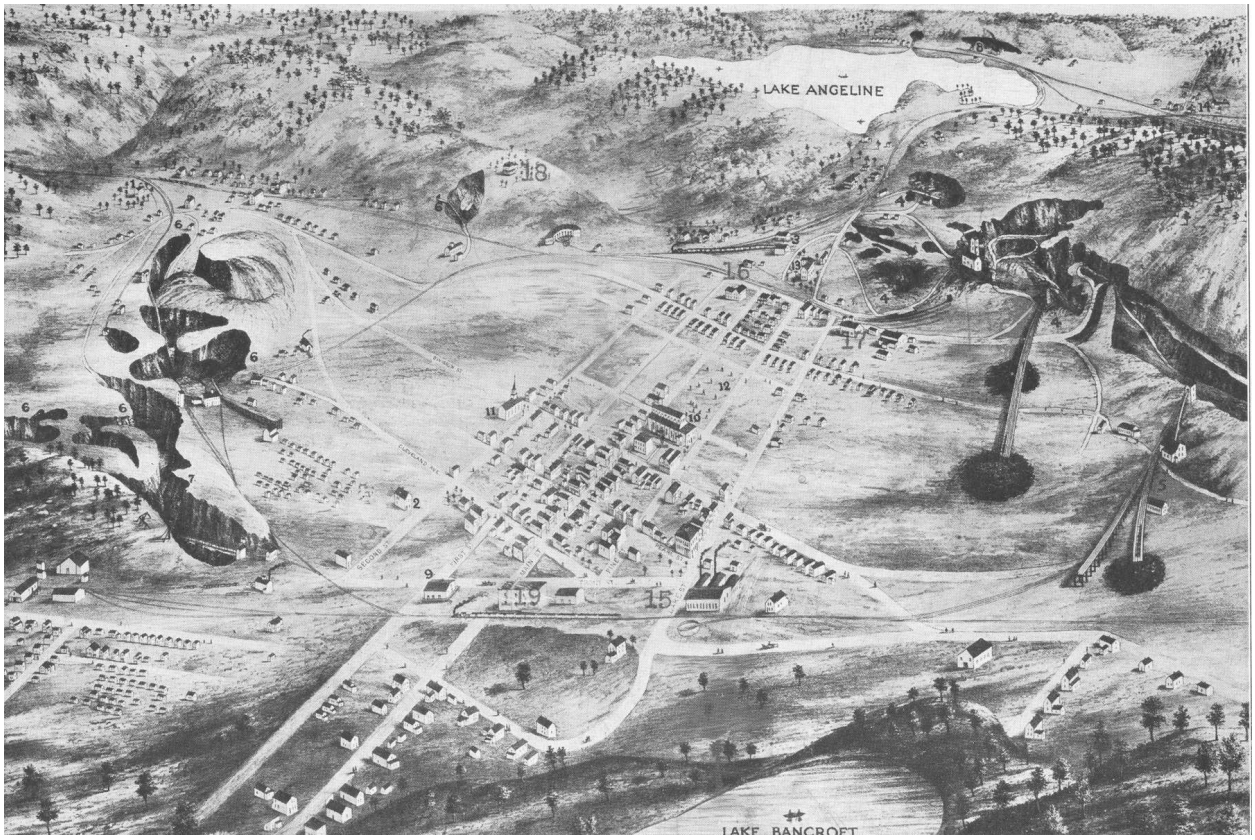
In summary, because Marquette Range iron miners first encountered nitroglycerin oil in the open air, they learned how to handle the touchy explosive under favorable conditions.[64] By the time most Michigan iron mines began to go underground—a process that accelerated in the mid-1870s—they had become accustomed to using blasting oil. Resistance to the material would likely have been more severe had the substance been introduced to the area a few years later.[65]

Social factors, particularly ethnic demographics, also contributed to the different responses on

the two ranges. Contemporary accounts strongly suggest that skilled Cornish miners led opposition to the introduction of nitroglycerin in both the Lake Superior copper and iron districts.[66] The anti-nitroglycerin poetry that appeared in the *Portage Lake Mining Gazette* before and after the Huron mine strike was written by an anonymous Cornishman.[67] An accident involving Cornish miners in 1870 set off the Washington mine strike, in which they were acknowledged as the prime movers.[68] Even before that strike, the Negaunee correspondent of the *Mining Journal* asserted: "It seems that the Cornish portion of the miners have a strong dislike toward the glycerine, as they say it injures their business."[69]

Cornish miners were the most skilled among the immigrant work force used in both regions. Coming from a centuries-old underground mining tradition in southwest England, they felt threatened by the new blasting material because they dominated the skilled drilling and blasting work in the mines. They faced two outcomes if the new material were adopted, neither good from their point of view. If they continued to do the blasting, they would have to use a material that caused severe headaches and had a dangerous reputation. If they turned the blasting over to specialists, the lost control of one of the key skills that distinguished them from common labor. In either case, the new and more powerful blasting compound threatened to reduce the number of miners required to sink shafts and drive drifts.

It was just these concerns—headaches, safety, loss of craft, and reduced employment—that led



Bird's-eye view, looking south, of the iron mining town of Ishpeming, Michigan, circa 1871. At the east edge of town, to the left, are the adjacent open pits of the Cleveland mine and the New York mine. At the west edge of town, to the right, are the open pits of the Lake Superior mine and the Barnum mine. (From: Proceedings of the Lake Superior Mining Institute *14 (1909): facing p. 202.)*

Cornish miners in the California gold mining region of Grass Valley to strike over the introduction of dynamite in 1869, a strike reported in Lake Superior newspapers.[70] Thus, it is not surprising that the Cornish on Lake Superior responded negatively to the introduction of nitroglycerin.

By 1870, the Cornish and English made up about 40 percent of all mine employees in Houghton County, the heart of the Lake Superior copper district. At some mines, like the Quincy, Cornish or English miners formed over half of the work force, and they were concentrated in underground work and skilled positions.[71]

Perhaps because Marquette Range mines had not yet gone underground, Cornish miners, with their underground experience and skills, had not yet established themselves there as firmly. Only 27 percent of the miners at three major Marquette-area mines in 1870 were Cornish or English.[72]

These figures suggest that the key ethnic group likely to oppose the introduction of nitroglycerin was less powerful in the iron region than in the copper region.[73] This circumstance may have been as important as technical issues in influencing the different receptions of blasting oil on the two ranges.

A final factor that contributed to the two ranges' divergent paths after 1870 was the sharply different tacks taken by organs of public opinion, i.e., regional newspapers. Newspapers in both regions enthusiastically printed stories and editorialized on the potential benefits of nitroglycerin until early 1870. They reacted differently in the aftermath of the nitroglycerin strikes, however.

Even before the strike, the *Portage Lake Mining Gazette*, the leading newspaper on the copper range, had printed several nice bits of poetic doggerel skeptical of nitroglycerin, written by an anonymous Cornish miner who signed himself "Powder Can" or "Cousin Jack." The paper had also expressed alarm about careless folk being allowed to handle powerful explosives, "no matter how safe they may consider them."[74] In January 1870 the *Gazette* published an editorial, titled "Is It Too Dangerous," commenting that even the inventor of nitroglycerin considered it too hazardous for general use.[75]

In view of the paper's steady shift away from its early endorsement of nitroglycerin, it is not surprising that at the Huron strike the *Gazette* turned completely against the substance, a position apparently shared by the community. In the *Gazette's* first report on the strike, it declared that while the strikers may have acted without sufficient cause "we can hardly blame them." The editor noted that two local chemists had declared nitroglycerin "absolutely dangerous."

After the miners won the strike by exploding the storage shed with glycerin in it, the *Gazette* admitted that the superintendent of the Huron mine and the contractors had taken every possible precaution to isolate work with blasting oil from the mine's regular employees, leaving the strikers no just cause for complaint. "Yet," the newspaper editorialized, "the sympathies of almost the entire community, including all our leading mining men, have been with the men." In the same issue, under the headline "Nitro-Glycerin Again," the paper reported a fatal explosion at a glycerin factory in the east.[76]

In late May 1870, after the Huron strike, the *Gazette* asserted that the superiority of glycerin "over good powder" had never been demonstrated, that "no sane agent" in the region would use it, and that if the Phoenix tried to use it again "we confidently expect, within thirty days, to announce another serious accident."[77]

The Phoenix, apparently alone among the region's mines after the Huron strike, continued to use high explosives. The *Gazette* wrote negatively of the results. In June it reported that two charges of nitroglycerin used at the Phoenix had seriously damaged the mine's timber work, but broke no more rock than average charges of black powder would have done.[78] When an explosion of dualin, a form of dynamite, occurred at the Phoenix mine, the *Northwestern Mining Journal*, another copper country paper just across the Portage Riv-

er from Houghton in Hancock, pleaded: "Throw the stuff away, you that are in authority."[79]

In stark contrast, on the iron range the leading paper, Marquette's *Mining Journal*, supported the use of nitroglycerin even during the Washington mine's strike, asserting that the accident that set off the strike would have occurred even if blasting powder had been used. In reporting on the Huron mine strike on the copper range, the *Mining Journal* criticized the *Houghton Mining Gazette's* sympathetic coverage, accusing that newspaper of placing itself squarely in sympathy with and in support of mob violence.[80] When *Scientific American* criticized blasting oil, the *Mining Journal* defended its use.[81]

One searches in vain in the *Mining Journal*, or the *Negaunee Mining Review*, for negative editorial commentary on nitroglycerin, if safely handled, in the early 1870s. Instead, one finds continuing assurances that blasting oil was safer than conventional blasting power, and that miners were steadily converting to its use.[82]

The net result of all of these factors was that adoption of high explosives moved full speed ahead on the Marquette Range, while copper range managers chose to stay with traditional explosive agents rather than upset their miners. Only between 1878 and 1880 did one of the leading mines on the copper range, the Quincy just north of Houghton, introduce high explosives, and then only gradually, after management became convinced that one of the newer solid forms was safe enough not to provoke miners' resistance.[83]

Ironically, when the copper range did begin to introduce high explosives, it had to purchase them from companies that produced them on the iron range, for the latter's more enthusiastic adoption had led several high-explosives companies to put roots down there by 1880. Only in the late 1880s did the copper region secure a factory to produce its high explosives.[84]

Ready acceptance of one technological innovation does not necessarily clear the way for the introduction of others, even closely related ones. While the iron mines embraced liquid nitroglycerin quickly, they responded more slowly to "improved" and "safer" forms of nitroglycerin, such as dynamite or other concoctions that combined nitroglycerin with an absorbent to convert it to a solid and less sensitive form. The iron range only shifted from liquid nitroglycerin to dynamite at about the same time that the copper range shifted from black powder to dynamite or its brother compounds: 1878 to 1880.

An anonymous account of a visit to the iron range by "A Stranger" in 1872 remarked on the use of nitroglycerin, but commented that "nothing seems to be known of Giant powder or Dynamite, which is successfully used on the Pacific coast [*sic*]," and was considered safer.[85] As late as 1878 liquid nitroglycerin seems to have been the explosive of choice, for a massive explosion near Negaunee that killed seven persons probably resulted from carelessness in loading liquid nitroglycerin on a special train that was to carry it to the Republic mine.[86]

The anonymous stranger, however, was mistaken. The region's iron mines did know about dynamite and its brother compounds. Thomas Brooks, conducting a geological survey of the iron range in the early 1870s, noted that dualin, a form of high explosive similar to dynamite, and giant powder—another name for dynamite—had both recently been introduced. In 1872 an agent of the Atlantic Giant Powder Company visited the area to introduce his product.[87] An inventory of the Cleveland Iron Mining Company in May 1875 indicates that the company had ninety-two pounds of giant powder on hand, in addition to black powder and nitroglycerin oil.[88] In 1876, a local mine captain invented a new form of dynamite, which he called "thunderbolt powder," that was adopted by the Jackson mine, and Jay Morse, who served as local business agent for several regional mines, reported in 1878 that he had tried a number of new high explosives, including giant powder.[89]

But prior to 1880, knowledge had not led to adoption. Nitroglycerin oil remained the explosive of choice. Why? As noted before, Marquette Range iron mines had to deal with very hard rock, making maximum explosive power important. Even the most powerful dynamites, which were essentially nitroglycerin absorbed in solids, were, pound for pound, 25 to 30 percent less powerful than the original product.[90]

Nitroglycerin oil was also cheaper than dynamite or its derivatives. These products, after all, started with nitroglycerin oil, but carried it through several extra steps that drove up the price. Nitroglycerin oil had to be absorbed by some substance—fuller's earth, sawdust, rotted wood, or even gunpowder—to convert it to a clay-like solid or semi-solid. Then this material had to be packed in a waterproof paper cylinder.[91]

Cost was a particularly important consideration for mine agents in the Lake Superior iron mines. Unlike their colleagues in the copper district, who dealt with a substance that solid by the pound, they dealt with a base metal that sold by the ton and had to be transported hundreds of miles for processing. Struggling with low ore prices in the aftermath of the Panic of 1873 and needing to hold mining costs down to have any hope of profit, the superintendents of iron mines undoubtedly found blasting oil's lower price very attractive.[92]

A final factor influencing the delay in adopting dynamite on the iron range seems to have been concern over getting dragged into litigation between Nobel-licensed companies and rivals who had created dynamite-like explosives by using an absorbent other than the kieselguhr (diatomaceous earth) used by Nobel.[93]

Conclusion

In his 1987 article on the introduction of mechanical rock drills on the Lake Superior copper range, Larry Lankton pointed out that while their adoption was partly conditioned by the need to adapt them to the hard rock of the copper district, existing social norms also influenced the acceptance of mechanical drills. Once adapted to mining conditions on Lake Superior, early forms of the drill met little opposition, for the drill required several men to move, erect, and operate it, thus keeping traditional mining teams together. However, later forms of the drill, which required only a single man to operate, met serous opposition because they threatened to break the traditional mining team apart.[94]

In some ways the differential response of the two mineral ranges on Lake Superior to liquid nitroglycerin was conditioned in the same manner. The technical advantages of nitroglycerin oil as a blasting compound were clear from the start on both ranges, but the response to those technical advantages was mitigated by other elements. The harder rock of the iron region played some role, but so did other factors.

The timing of the material's introduction was critical. Nitroglycerin came to the copper mines after they were hundreds of feet underground. The material's noxious fumes, its susceptibility to deterioration and to explosion by sudden impact, the consequent difficulties in handling it safely, and the intensity of its explosions were causes for special concern underground. Glycerin oil reached the iron mines just before most went underground. The prevailing open pit operations on the iron range circa 1870 reduced these objections to blasting oil, and gave miners a comparatively better and safer environment in which to become accustomed to the new explosive and the methods for safely handling it.

Social factors are also central to understanding the differential diffusion of nitroglycerin. Cornish miners had traditionally both drilled and blasted rock. With the coming of nitroglycerin they faced two equally uninviting alternatives. They could agree to use the new blasting agent and subject themselves to the headaches that seemed to come with its use and to the dangers that seemed inherent in the unstable liquid. Or

they could agree to delegate blasting to independent contractors, like Jacob Houghton and the Mabbs brothers, or to company-designated blasting specialists, but thereby relinquish some of the skills that had traditionally put them in high demand. Making matters worse, the greater explosive power of nitroglycerin threatened to shrink the demand for skilled miners due to the reduced drilling required for blasting.

Not surprisingly, the Cornish, who dominated the skilled mining positions in the Lake Superior mining districts, resisted high explosives. They could see no advantage to accepting them. The higher concentration of Cornish in the copper district gave them greater influence there.

Finally, the consistent vocal support given to the new explosive by the leading organs of public opinion in the iron region, and the negative attitude expressed by the parallel newspapers in the copper region, contributed to an atmosphere that made it easier to continue using nitroglycerin in the iron region than in the copper region.

Thus, the particular environment into which a technological innovation is diffused strongly influences the reception that innovation is likely to receive. In the case of mining that environment clearly includes not only the nature of the rock being mined, but also the mode of mining, the timing of the introduction of the innovation, and a variety of social factors such as labor demographics, traditions of work, and the influence of local organs of public opinion.

The differential acceptance of high explosives between the copper and iron ranges on Lake Superior had at least one long-term repercussion: the location of the region's explosives industry. The ready acceptance of high explosives on the Marquette Range meant that manufacturers of high explosives erected their plants around the iron mining towns of Ishpeming and Negaunee rather than near the copper mining towns of Calumet, Houghton, or Hancock. Bill Haller, who published a recent study of the explosives industry that eventually supplied Michigan's copper range, found that, of nineteen explosive manufacturers that he could identify as operating at one time or another on Michigan's Upper Peninsula, fourteen located on the Marquette Iron Range, only two on the Keweenaw Copper Range.[95]

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Notes:

1. *Mining Journal* (Marquette, MI), 12, 19 and 26 Feb. 1870; *Mining Journal* [Weekly edition], 1 Dec. 1906 (contains an interview with a miner who had worked in the Washington at the time of the strike); *Portage Lake Mining Gazette* (Houghton, MI), 10 and 24 Feb. 1870.
2. *Mining Journal*, 26 Mar. 1870.
3. *Portage Lake Mining Gazette*, 21 and 28 April 1870; Graham Pope, "Some Early Mining Days at Portage Lake," *Proceedings of the Lake Superior Mining Institute* 7 (1901): 30. Because local papers regularly published items relating to nitroglycerin, the miners were probably well aware that the substance deteriorated with age and became more sensitive to accidental detonation. The glycerin used by the Mabbs brothers at the Huron had been imported the previous August (*Portage Lake Mining Gazette*, 5 Aug. 1869) for use in the Aztec and Isle Royale mines. The Isle Royale was shut down for economic reasons by its directors just after its trial of nitroglycerin began.
4. Mark Wyman, *Hard Rock Epic: Western Miners and the Industrial Revolution, 1860-1910* (Berkeley: University of California Press, 1979), 104; Otis E. Young, Jr., *Western Mining* (Norman: University of Oklahoma Press, 1970), 212; Eric Twitty, *Blown to Bits in the Mine: A History of Mining and Explosives in the United States* (Ouray, CO: Western Reflections Publishing Co., 2001), vii, 1-2.
5. Bill Van Kosky, "Negaunee's Nitro-Glycerine Tragedy," *Michigan History* (Nov.-Dec. 2009): 48-53. In fact, regional mining agents rallied around the continued use of nitroglycerin oil, proclaiming that, if handled correctly, it was safer than traditional blasting power. See the *Mining Journal* (26 Jan. 1878) for defense of nitroglycerin use.
6. A number of contemporary sources discuss the advantages and potential cost savings of nitroglycerin, including: Edward P. North, "Blasting with Nitro-Glycerine," *Transactions of the American Society of Civil Engineers* 1 (1872): 13-21; Stephen Chester, "Nitro-Glycerin–Its Manufacture and Use," *ibid*., 117-34; and Walter N. Hill, *Notes on Certain Explosive Agents* (Boston: John Allyn, 1875), 32-66.
7. For the early history of nitroglycerin see: Herta E. Pauli, *Alfred Nobel: Dynamite King—Architect of Peace* (New York: L. B. Fischer, 1942); Henry S. Drinker, *A Treatise on Explosive Compounds, Machine Rock Drills and Blasting* (New York: John Wiley and Sons, 1883), 65-71; Twitty, *Blown to Bits in the Mine*, 12-19; Arthur Pine VanGelder and Hugo Schlatter, *History of the Explosives Industry in America* (New York: Columbia University Press, 1927), 315-90; and Manuel Eissler, *The Modern High Explosives* (3rd ed., New York: John Wiley, 1899), 38-9.
8. "Evidence of Otto Burstenbinder" in: George H. Mowbray, *Tri-Nitro-Glycerin as applied in the Hoosac Tunnel, Submarine Blasting, Etc.* (North Adams, MA: James T. Robinson and Son, 1872), 78-9. VanGelder and Schlatter, *History of the Explosives Industry,* 324; Pauli, *Alfred Noble*, 87.
9. Otis E. Young, Jr., *Black Powder and Hard Steel: Miners and Machines on the Old Western Frontier* (Norman: University of Oklahoma Press, 1976), 40; Wesley S. Griswold, *A Work of Giants: Building the First Transcontinental Railroad* (New York: McGraw-Hill, 1962), 146-7.
10. "The Late Terrible Disaster" (*Mining and Scientific Press*, 12 (21 Apr. 1866): 248) discusses at length the San Francisco accident.
11. Good biographies of Nobel with considerable information on his stay in America are: Pauli, *Alfred Nobel*; and Kenne Fant, *Alfred Nobel: A Biography* (New York: Arcade Publishing, 1993).
12. Mowbray, *Tri-Nitro-Glycerin,* 10-50.
13. Frederick A. Abel, "Explosive Agents applied to Industrial Purposes," *Institution of Civil Engineers, Minutes of Proceedings* 34 (1871-72): 345; VanGelder and Schlatter, *History of the Explosives Industry*, 330-6.
14. John R. Gilliss, "Tunnels of the Pacific Railroad," *Transactions of the American Society of Civil Engineers* 1 (1872): 162-3, 168-70; David Howard Bain, *Empire Express: Building the First Transcontinental Railroad* (New York: Viking, 1999), 272-5, 315-21, 605, 606; Griswold, *Work of Giants*, 146-7, 193-5, 302.
15. Pauli (*Alfred Nobel*, 86-7) notes that Burstenbinder, with little prior experience with explosives, acquired knowledge of nitroglycerin when on a visit to the old country, brought samples back with him in his luggage, and used demonstrations to promote the creation of a stock company. Pauli does not mention Burstenbinder's visit to the Marquette Iron Range.
16. "Testing the Merit of Blasting Oil," *American Mining Gazette* 3 (Sep. 1866): 437-40.
17. *Negaunee Mining and Manufacturing News* (Negaunee, MI), 19 Dec. 1867. The experiments of late 1866 are noted briefly in this issue. No regional papers survive from early 1866, so a contemporary account of the earlier experiments could not be discovered.
18. A brief, somewhat inaccurate, sketch of Jacob Houghton can be found in: "Jacob Houghton," *Proceedings of the Lake Superior Mining Institute* 15 (1910): 214-5.
19. *Mining Journal*, 21 Aug. 1869; *Lake Superior Miner* (Ontonagon, MI), 14 Aug. 1869; *Portage Lake Mining Gazette*, 16 Aug. 1869.
20. *Mining Journal*, 28 Aug. 1869 (see also issue of 11 Sep. 1869 for further shipments from Painesville, Ohio, to the Marquette Iron Range).
21 *Mining Journal*, 23 Oct. 1869.
22 See *Mining Journal*, 6 Nov. 1869 and 1 Jan. 1870, for

the Jackson and Washington mines; *Portage Lake Mining Gazette* (18 Nov. 1869) reported that Dan Northy was moving to Marquette to superintend the use of nitroglycerin at the Cleveland mine.

23. "Copper, Michigan," *American Journal of Mining* 4 (24 Aug. 1867): 116; *Portage Lake Mining Gazette*, 19 Dec. 1867; "Directors' Statement to the Stockholders, Dec. 11, 1867, Phoenix Copper Company," p. 15, in Folder 21, Box 10, Calumet & Hecla Abstract Collection, MS-048, Michigan Tech Archives and Copper Country Historical Collections, Houghton, Michigan. *The Lake Superior Miner* (8 and 15 Feb. 1868) also commented that the Phoenix was the only copper mine on Lake Superior using nitroglycerin, and suggested that it might even be the only copper mine in the world using it. Alfred Nobel's article "Dynamite, the New Blasting Agent" (*Merchant's Magazine* 59 (Oct. 1868): 255) reprinted a 2 Feb. 1868, letter from J. G. Jackson, manager of the Phoenix mine, reporting that by that date the Phoenix had already used seven thousand pounds of nitroglycerin.
24. *Engineering and Mining Journal*, 5 (27 June 1868): 404, for Copper Falls; *Lake Superior Miner,* 4 Sep. 1868 and 5 Aug. 1869, for Aztec; Pope, "Some Early Mining Days," 30; *Portage Lake Mining Gazette*, 28 Apr. 1870 (a letter to the editor by John Mabbs, Daniel Northy, and Austin Mabbs mentions use in the Isle Royale mine the previous fall).
25. "Directors' Statement to the Stockholders, Dec. 11, 1867," 15-6.
26. *Lake Superior Miner,* 21 Aug. 1869 (see also 9 Oct. 1869); *Lake Superior Mining and Manufacturing News* (Negaunee, MI), 20 Feb. 1868. See also "Lake Superior," *American Journal of Mining* 5 (11 Jan. 1868): 24-5: "We notice that nitro-glycerine is being tried in some [mines in the copper region], and that a great reduction of mining cost, by its use, is reported."
27. *Mining Journal*, 1 and 29 Jan., and 5 Feb. 1870; *Portage Lake Mining Gazette,* 13 and 27 Jan., and 3 Feb. 1870.
28. For examples see: *Lake Superior Miner*, 8 Feb. 1868 and 21 Apr. 1869; *Portage Lake Mining Gazette*, 21 Apr. 1870; *Mining Journal*, 21 Aug. 1869, and 1 Jan. and 26 Mar. 1870.
29. *Portage Lake Mining Gazette*, 26 Sep. 1868.
30. Contemporary papers did not report this. A former employee of the Aztec, James Heard, interviewed in 1906, reported that he quit the mine soon after glycerin oil was introduced and that "nearly everyone working at the Aztec at that time pulled out." See *Mining Journal* (weekly), 1 Dec. 1906, under the headline "Burley Rock Drill."
31. "Copper, Michigan," *American Journal of Mining* 5 (27 June 1868): 404.
32. *Portage Lake Mining Gazette*, 5 Aug. 1869.
33. *Portage Lake Mining Gazette*, 26 Aug. 1869 (for opposition to its landing in Houghton), and 28 Apr 1870 (for passing mention of the opposition of Isle Royale miners to its introduction in the fall of 1869 in a letter to the editor on 'The Huron Strike' from John Mabbs, Daniel Northy, and Austin Mabbs).
34. *Mining Journal*, 12 Jan. 1870.
35. In addition to the strike at the Huron mine, a second anti-nitroglycerin strike occurred on the copper range in late May or early June at the Phoenix mine. Sketchy reports indicate that the blasting contractor was "in rather a warm situation" for two or three days, and suggest that local management at the Phoenix, unlike the Huron, were successful in suppressing this strike. See: *Portage Lake Mining Gazette*, 2 June 1870; *Mining Journal*, 4 June 1870; and Phoenix Mining Company, "Report of the Directors of the Phoenix Copper Co. for the year ending Dec. 31st 1870," Calumet and Hecla Abstract Collection, folder 21, Box 10, MS-048, Michigan Tech Archives and Copper Country Historical Collections., Houghton, MI.
36. William B. Gates, *Michigan Copper and Boston Dollars: An Economic History of the Michigan Copper Mining Industry* (Cambridge, MA: Harvard University Press, 1951), 58; Larry D. Lankton, *Cradle to Grave: Life, Work, and Death at the Lake Superior Copper Mines* (New York: Oxford University Press, 1991), 96-7; Charles K. Hyde, *Copper for America: the United States Copper Industry from Colonial Times to the 1990s* (Tucson: University of Arizona Press, 1998), 63; and Larry D. Lankton and Charles K. Hyde, *Old Reliable: An Illustrated History of the Quincy Mining Company* (Hancock, MI: The Quincy Mine Hoist Association, Inc., 1982), 60.
37. *Mining Journal*, 11 June 1870 ("Our Houghton Letter").
38. *Northwestern Mining Journal* (Hancock, Mich.), 18 Feb. 1874.
39. Reprinted in the *Mining Journal*, 11 Jan. 1873, from the *Portage Lake Mining Gazette*. No issues of the *Mining Gazette* itself survive from late 1872 and early 1873.
40. Thomas Egleston, "Copper Mining on Lake Superior," *Transactions of the American Institute of Mining Engineers* 6 (1877-78): 284, 290. Manuel Eissler (*The Modern High Explosives*, 48) noted that workmen using nitroglycerin got headaches.
41. *Mining Journal*, 26 March 1870.
42. See *Mining Journal*, 11 June 1870, for use at the Edwards and New England mines. See E. B. Isham to W. M. Gaylord, 16 July 1870, Letters out from Superintendent 1870-1873, Folder 1, Box 40, Iron Cliffs Company Papers, RG 68-102, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University Repository, Marquette, MI, and also *Mining Journal,* 4 Aug. 1870, for the decision to use it at

the Barnum mine.

43. Thomas B. Brooks, "An Analysis of the Cost and Description of the Methods of Mining Employed in the Marquette Iron Region, Lake Superior, Michigan," *Transactions of the American Society of Civil Engineers* 2 (1873): 26. Brooks gives a different figure in: T. B. Brooks, et al., *Geological Survey of Michigan: Upper Peninsula 1869-1873*, v. 1 (New York: Julius Bien, 1873), 268-9. There he says $40,000 worth was sold in the Marquette region at $1.50 a pound in 1870, and that in 1872 around 40,000 pounds were used at a price of $1.25 per pound.
44. *Mining Journa*l, 3 Dec. 1870; A. P. Swineford, *Swineford's History of the Lake Superior Iron District* (2nd ed., Marquette: Mining Journal Office, 1871), 27. Mills would admit in a letter to the company's business agent complaining about mine fuses that he did not "fancy" having to go down and clean out blasting holes filled with nitroglycerin after they had failed to fire. See: Frank P. Mills to Jay C. Morse, 25 Jan. 1872, Item 2772, Cleveland Iron Mining Company and Cleveland-Cliffs Iron Company Papers, MS 86-100, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University.
45. *Mining Journal*, 11 June 1870.
46. *Negaunee Mining Review,* 4 Aug. 1870. *The Mining Journal* (21 Sep. 1872) reported daily conversions of miners to the use of the nitroglycerin for blasting with each convert "more enthusiastic than the preceding one."
47. *Mining Journal*, 15 Mar. 1873.
48. *Mining Journal*, 17 Jan. 1872.
49. "To the Board of Directors of the Washington Iron Co., 1874 Annual Report," Folder 3, Papers, 1888-1903, concerning misc. subjects, Box 22, Peter White Papers, Bentley Library, Ann Arbor, MI. The report indicates that the company used 7,562 pounds of nitroglycerin and 200 kegs of powder. Kegs of black powder varied from twenty to twenty-five pounds. At twenty-five pounds, the Washington used 5,000 pounds of traditional blasting powder. Jacob Houghton believed that nitroglycerin was blasting down at least as much rock in the iron district as black powder in 1878, see *Mining Journal*, 26 Jan. 1878 (letter to the editor).
50. Reprinted in: Thomas Dunlap, *Wiley's American Iron Trade Manual* (New York: John Wiley and Son, 1874), 467.
51. "The Marquette Iron Region," *School of Mines Quarterly* 3 (1881-82): 199. Roger Burt ("Innovation or Imitation?: Technological Dependency in the American Nonferrous Mining Industry," *Technology and Culture* 41 (2000): 334) says that the introduction of high explosives closely tracked the adoption of machine drilling, with the new explosives piggybacking on the drill and that "nowhere did they come into common use before the 1880s." His statement may be true in nonferrous mining, but clearly high explosives were in common use on the Michigan iron range well before 1880.
52. *Mining Journal*, 19 Nov. 1870; see also 26 Nov. 1870 (for the arrival of chemicals and machinery), and 21 Jan. 1871 (for a description of the plant in operation near Marquette). The destruction of the company's northern Ohio plant by explosion helped influence the timing of the move. See also: C. C. Cowpland, "A Resume of the Early History of the Explosives Industry in Marquette County," *Proceedings of the Lake Superior Mining Institute* 29 (1936): 22.
53. *Mining Journal*, 4 Nov. 1871, 13 and 20 Jan. 1872 (the Marquette Nitroglycerin Company); Cowpland, "Explosives Industry in Marquette County," 24.
54. "Sept. 1, 1875, Washington Iron Co. Property in care of H. B. Tuttle & Co.," Folder: Papers, Sept. 1875, Box 2, Peter White Papers, Bentley Library; *Michigan State Gazetteer and Business Directory 1877* (v. 3, Detroit: R. L. Polk and Co., 1877, 506) lists "Alto Burstenbinder, mnfr. of nitro-glycerine"; Cowpland ("Explosives Industry in Marquette County," 25) and VanGelder and Schlatter (*History of the Explosives Industry*, 393) say Billy Code operated a small plant on the Marquette range in the 1870s, first at Humboldt and later at nearby Clarksburg.
55. *Negaunee Iron Herald*, 21 Sep. 1876.
56. *Negaunee Iron Herald*, 11 Jan. 1877.
57. John W. Foster, *The Geology and Metallurgy of the Iron Ores of Lake Superior, being a Report Addressed to the Board of Directors of the Iron Cliffs Company* (New York: W. C. Bryant & Co., 1865), 34-5.
58. Foster, *Geology and Metallurgy of the Iron Ores of Lake Superior*, 35; A. P. Swineford, *History and Review of the Copper, Iron, Silver, Slate and other Mineral Interests of the South Shore of Lake Superior* (Marquette, MI: The Mining Journal, 1876), 156.
59. Dunlap, *Wiley's American Iron Trade Manual*, 467. Perhaps Swineford's comment applied to an attempt to drill through a jaspilite incursion, rather than in the ore itself.
60. Egleston, "Copper Mining on Lake Superior," 290.
61. "Blasting," *The New American Cyclopaedia*, v. 3 (New York: C. D. Appleton and Co., 1870), 338.
62. Based on extended conversations with Professor of Civil Engineering Stan Vitton, a rock mechanics specialist at Michigan Tech with experience in drilling both types of rocks. My thanks also to several other regional geologists and engineers who discussed this problem with me, including Theodore Barnhorst, Murray Gillis, John McKana, and Bill Haller. A 1930 master's thesis at the Michigan College of Mining and Technology also suggests that hard-ore iron mines drilled harder rock than the copper mines, noting the slightly greater diameter of drill shanks used on the iron range. See: Donald Everson Palmer, "The Treatment and use of Drill Steel in Copper and

Iron Mines of the Lake Superior District" (M.S. thesis, Michigan College of Mining and Technology, 1930), 28.

63. In 1878, J. C. Fowle, superintendent of the Michigamme mine, some ten miles further west than the Washington, complained of poorly made nitroglycerin explosives, in this case a form of dynamite, that "it smells so our men are sick from using it. In an open pit the smell does not trouble but underground we cant [*sic*] use it." See: J. C. Fowle to James Rood, 26 Aug. 1878, Item 2725, Cleveland Iron Mining Company and Cleveland-Cliffs Iron Company Papers, MS 86-100, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University.
64. It should be noted that the Washington mine was partially an underground operation. The deposit, located on a bluff, was developed by open pit excavation at the top and simultaneous excavation of a haulage adit at the bottom of the bluff. Shafts were driven from operations at the top to the adit level to ease loading ore cars.
65. Hypothetically, had nitroglycerin been introduced a decade later on the iron range, yet another factor might have worked against its rapid adoption. By the 1880s the much softer red hematite ore, which tended to be lower in phosphorus and easier on blast furnace linings, had begun to displace in popularity the hard specular hematite, which had been the primary ore mined on the Marquette Range since its opening in the mid 1850s. Drilling and blasting the soft red hematite required much less effort than extracting specular hematite.
66. This was also the case when high explosives were introduced in California. For Cornish opposition at Grass Valley, California, to dynamite, an explosive containing nitroglycerin, see: Daniel Cornford, "'We All Live More Like Brutes than Humans': Labor and Capital in the Gold Rush," in James J. Rawls and Richard J. Orsi, *A Golden State: Mining and Economic Development in Gold Rush California* (Berkeley: University of California Press, 1999), 96-8; and Richard E. Lingenfelter, *The Hardrock Miners: A History of the Mining Labor Movement in the American West 1863-1893* (Berkeley and Los Angeles: University of California Press, 1974), 18, 83-90.
67. *Portage Lake Mining Gazette*, 26 Aug. and 2 Sep. 1869, and 5 May 1870. The author signed himself "a cousin Jack" and employed Cornish characters using Cornish dialect in the poems.
68. *Portage Lake Mining Gazette*, 10 Feb. 1870 (from its Negaunee correspondent).
69. *Mining Journal*, 15 Jan. 1870. For a similar remark see: *Portage Lake Mining Gazette*, 13 Jan. 1870. Burt ("Innovation or Imitation?", 344) notes, more generally, that one of the most conservative influences on western mining practice was the dominance of European, principally British, miners and their traditional apprenticeship-training tradition.
70. For reports of the Grass Valley, California, strike see: *Portage Lake Mining Gazette*, 2 Sep. 1869, and *Lake Superior Miner*, 12 June 1869. *The Mining Journal* (27 Jan. 1872) commented that the principal opposition was from miners who saw it as not only something "extremely dangerous," but also as something "intended to reduce the number and wages of those employed in the mines." Cornish miners in Britain also reportedly resisted nitroglycerin—or anything else new. For this see: Rossiter W. Raymond, *Statistics of Mines and Mining in the States and Territories West of the Rocky Mountains*, v. 4 (Washington: U.S. Government Printing Office, 1873), 488.
71. Lankton and Hyde, *Old Reliable*, 39; U.S. Census Office, Ninth Census of the United States, 1870, I (Washington, 1872), 359.
72. Brooks, *Geological Survey of Michigan*, 251.
73 Ronald H. Limbaugh ("Making Old Tools Work Better: Pragmatic Adaptation and Innovation in Gold-Rush Technology" in Rawls and Orsi, *A Golden State*, 37) suggests that California mining districts lacking strong Cornish labor representation made a smoother transition to high explosives. Cornford ("Labor and Capital in the Gold Rush," 96-8) sees Cornish clannishness and pride as key to explaining the initially successful resistance to the introduction of dynamite in Grass Valley.
74. *Portage Lake Mining Gazette*, 28 Oct. 1869 (for the quote. For the poetry see note 67 above).
75. *Portage Lake Mining Gazette*, 27 Jan. 1870.
76. *Portage Lake Mining Gazette*, 14 and 21 Apr. 1870.
77. *Portage Lake Mining Gazette*, 26 May 1870.
78. *Portage Lake Mining Gazette*, 23 June 1870.
79. *Northwestern Mining Journal* (Hancock, MI), 18 Feb. 1874.
80. *Mining Journal*, 14 May 1870 (and 4 June 1870 for the correspondence from Houghton).
81. *Mining Journal*, 26 Nov. 1870.
82. For example, *Mining Journal*, 21 Sep 1872.
83. Lankton, *Cradle to Grave*, 96-7; Lankton and Hyde, *Old Reliable*, 61.
84. Cowpland ("Explosives Industry in Marquette County," 25) notes that when mines on the copper range began to use nitroglycerin they had to import it from the plants already located on the iron range. A small schooner delivered it.
85. *Mining Journal,* 20 Sep. 1871.
86. *Negaunee Iron Herald*, 3 and 10 Jan. 1878; *Mining Journal*, 5 and 26 Jan. 1878.
87. *Mining Journal*, 5 Oct. 1872.
88. Brooks, *Geological Survey of Michigan*, 269; "Cleveland Iron Mining Co., Statement of Condition, Inventory, etc., May 18, 1875," Cleveland Iron Mining Co., Annual Statements, 1867-1890, Item 2749, MS 86-100, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University.

89. *Mining Journal*, 19 Feb. 1876 (for "thunderbolt powder") and Jan. 26, 1878 (for the Jackson mine's use of a nitroglycerin-based explosive); Jay C. Morse to I.(?) H.(?) King, 1 Sep. 1878, McComber Iron Co., Letter Book, 1878-1881, Item 2472, MS 86-100, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University.
90. Frederick W. Clark, "Some Tests of the Relative Strength of Nitro-Glycerine and Other Explosives," *Transactions of the American Institute of Mining Engineers* 18 (1889-90): 525-6.
91. Ira O. Baker (*A Treatise on Masonry Construction* (New York: Robert Drummond, 1899), 121, 123) placed the price of liquid nitroglycerin at from 15.5 to 19 cent per pound (50 to 60 cents per quart) and 75 percent nitroglycerin dynamite at 50 cents per pound. Before the expiration of Nobel's dynamite patent c. 1881 the differential would probably have been even greater. The *Report of the Department of Mines, Nova Scotia, for the year 1876* (Halifax, NS: Nova Scotia Printing Co., 1877), 42) commented that the high price of dynamite mitigated against its extensive use in mining.
92. Blasting oil's low price proved attractive in other venues as well. In the late 1870s and early 1880s the Canadian Pacific Railroad deliberately chose to use nitroglycerin oil, despite its safety shortcomings, because of its lower cost compared to dynamite. Pierre Berton, *The Impossible Railway: The Building of the Canadian Pacific* (New York: Alfred A. Knopf, 1972), 169-70, 381; and Christian Wolman, *Blood, Iron, & Gold: How Railways Transformed the World* (New York: Public Affairs, 2010), 149. Jack Kelly ("Big Bang: The Deadly Business of Inventing the Modern Explosives Industry," *American Heritage of Invention and Technology* 22, no. 1 (Sum. 2006): 44) says Mowbray sent one hundred thousand pounds of nitroglycerin oil to Manitoba for railroad blasting in 1877, with the shipment traveling by train, boat, two-wheeled bull cart, and, finally, on men's backs.
93. For evidence of mine agents' concerns over patent issues and possible litigation involving dynamite see: T. J. Houston to C. J. Canda, 27 Feb. 1878, Letters from T. J. Houston, General Manager, 1878-1879, Box 11; Alfred Rix, Atlantic Giant Powder Co., to C. J. Canda, May 22, 1879, Folder 7, Box. 2; George O. Houston to C. J. Canda, Nov. 27, 1880, Folder 9; C. J. Canda to A. W. Maitland, May 9, 1881, Letters Out by C. J. Canda, Dec. 1880-Jan. 1882, v. 19, RG 66-36; Iron Cliffs Company Papers, RG 65-37, Cleveland Cliffs Collections, Archives of Michigan, Northern Michigan University.
94. Lankton, "The Machine under the Garden: Rock Drills Arrive at the Lake Superior Copper Mines, 1868-1883," *Technology and Culture* 24 (1983): 1-37.
95. Bill Haller, e-mail to the author, 5 Mar. 2010, with a map showing the approximate locations of these plants. The remaining three explosives plants were located on two other Upper Peninsula iron ranges, the Menominee and the Gogebic. These ranges became important only in the 1880s, after the explosives industry had centered its operations on the Marquette Range. Haller's book is *Atlas Powder in Sinter, Michigan* (Houghton, MI: B. Haller, 2007).