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## Final Report

# Location and Stability Analysis of the Michigamme Underground Mine for the US-41 Re-Alignment in Marquette County, Michigan

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16. Abstract A proposed realignment of US-41 near Michigamme, Michigan will be located over an abandoned underground iron ore mine. The mine, known as the Michigamme Mine, was started in 1872 and closed in 1901. Initial mining operations were started in seven open pit mines but soon reverted to underground mining operations. There were at least ten production and ventilations shafts constructed at the mine. While the general locations of the shafts are known, the exact locations of some shafts are not. This is due in part to the filling in of the mine shafts with waste rock from the mining operations. The purpose of this report was to determine the location of the shafts and to make an evaluation of the stability of the surface with respect to the highway realignment. After investigating mine maps and historical documents it was determined that the realignment will not be affected by the underground mines. The only issue noted is that the highway will be adjacent to one of the shallower mine shafts. Mine maps indicate that this shaft is between 50 and 100 feet deep but filled with mine rock. The exact location of this mine shaft will need to be determined and structurally stabilized.					
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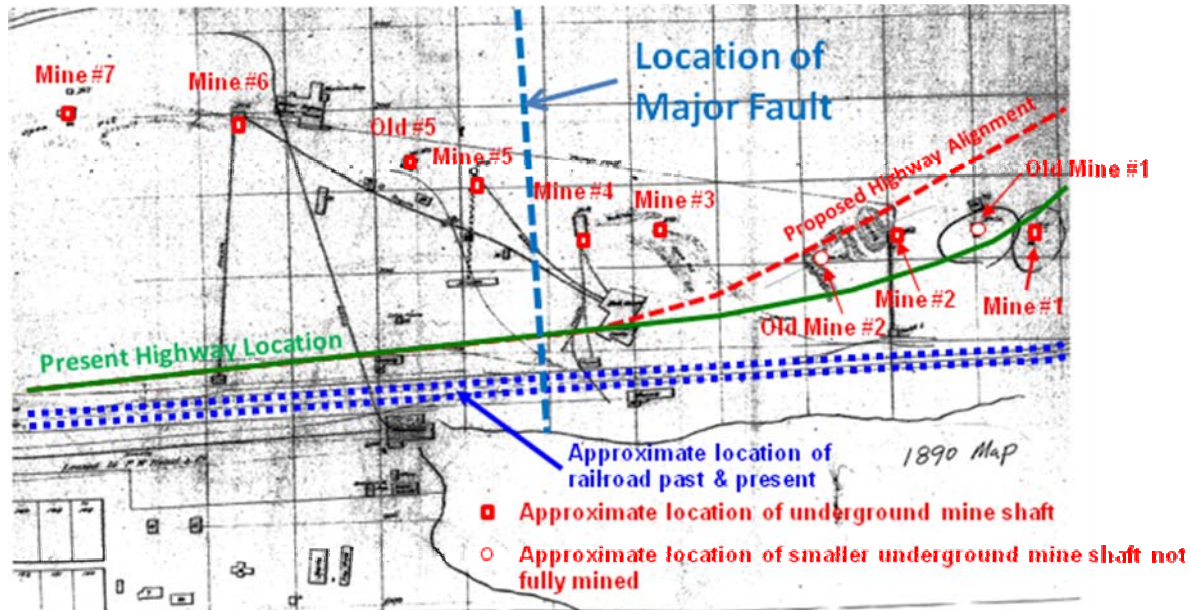
## **INTRODUCTION**

A section of US-41 east of Michigamme, Michigan is being relocated to decrease the horizontal and vertical curvature of the roadway. The western end of the highway re-alignment, however, crosses over an abandoned underground iron mine known as the Michigamme Mine. This mine opened in 1872 and closed in 1901, although iron ore shipments continued through 1905 with the ore coming from stockpiles and the processing of waste rock piles. The Michigamme Mine operations were started in seven open pits numbered 1 through 7 following the strike of the ore body from the east to the west. The iron ore body dips to the south towards Michigamme Lake at an angle of about 55°. In 1874 the mine started underground mining. Figure 1 shows the approximate location of the mine shafts. While the shafts have been filled with mine rock, there are concerns about the stability of the mine where the highway passes over the mine workings and possible effects from blasting that could cause settlement of the rockfill dumped in the abandoned shafts. The purpose of this report is to provide an assessment of the location of the mine shafts and the stability of the surface over the underground mines as it pertains to the relocation of the highway.

## **SUMMARY AND CONCLUSIONS**

An effort was made to collect as much information on the Michigamme Mine as possible. However, only one underground mine map showing the extent of underground mining for the Michigamme Mine, dated 1882, was obtained from the Cleveland Cliffs Mining Company (CCI) (via the MDOT Ishpeming office). This map indicates that most of the mining was conducted in the No. 4 mine shafts followed by the No. 5 and No. 6. The majority of the ore mined at the Michigamme Mine, approximately 60%, was mined between 1872 and 1882. The No. 4 and 5 mines were the deepest and most developed reaching a depth of over 1,000 feet. The most comprehensive information on the Michigamme Mine came from the Michigan Commissioner of Mineral Statistics reports, which were written periodically during the operational period of the mine, and two reports written by A.P. Swineford (1881, 1882).

The highway relocation will cross over the eastern end of the mine near the old No. 2 mine shaft and the main No. 2 shafts. The No. 1 and old No. 1 shafts are located to the east of the No. 2 shafts and should not impact the new highway alignment. According to the mine reports these shafts have been filled with rock. However, as with all old mine sites there is always the possibility that some shafts are not identified on the maps so care should be taken when conducting operations over the abandoned mines. It is unlikely, though, that additional shafts exist that have not been identified in this report. If they do exist, they will most likely be shallow and filled with rock.



**Figure 1** The 1890 Mine Layout of the Michigamme Mine.

Conclusions reached in this study are as follows:

1. The stability of the Michigamme underground mines in general appear to be very good. There were no major mine collapses found in the literature or evidence of ground collapses at the mine site from the underground workings. The primary reason for the mine's good stability was that it had a competent hanging wall consisting of quartzite. However, there is a significant fault separating the Nos. 4 mine shaft and the No. 5 shaft. Development drifts were made through the fault at the tenth level of the No. 4 shaft through to the new No. 5 shaft in 1882. There was no mention of ground instability from this mining. The only mention of "poor ground" was in the Nos. 1 and 2 shafts where the iron ore was erratic and where the ore was not located adjacent to the quartzite rock as in the other mine shafts.
2. However, there are a number of fenced in areas with signs posted indicating "caving ground." The caving areas result from the filling in of the shafts with mine rock and other debris. While some of the shafts might be totally filled in with this material, it is possible (and highly likely) that most of the shafts are not. It is probable that the rock at some portion in the shaft is "choked off" and that periodic slippage will occur resulting in sinkholes at the surface or "caving ground". This was observed in the spring of 2007 in the vicinity of the No. 4 shaft area where a sinkhole formed. The No. 4 shaft was one of the deepest and extensively mined at the Michigamme Mine. However, it is not clear that this sinkhole was the No. 4 shaft. It is more likely that this sinkhole formed over a "ventilation" shaft 125 feet to the west of the main No. 4 shaft.

3. It is possible that blasting might generate some settlement of the rockfill in the shafts. Therefore, care should be taken during blasting operations not to locate equipment or personnel near or adjacent to the shafts. The problem is that the exact locations of these shafts are not known. However, the data provided in this report can provide guidance as to their “probable” locations.
4. The current highway alignment passes over underground mine workings from the Nos. Old 1, 2, 4, 5 and 6 mine shafts as shown in Figure 1. Figure 2 shows the distances between each of the mines, while Figure 3 shows the 1882 underground mine with additional distances indicated on the maps. The most extensive underground workings are from the No. 4 shaft at a depth of approximately 1000 feet. The workings are located where the new alignment and the present mine come together on the west end of the proposed alignment. These underground workings have been stable for over 120 years.
5. The highway relocation will pass near and possibly over the old #2 shaft and possibly relatively close to the main #2 shaft. The #2 shaft is (most likely) located on the south side of the proposed highway alignment. This shaft has workings to a depth of about 300 feet but only had limited mining. The #2A shaft appears to be an exploratory shaft and was developed to a depth of 80 feet. According to the reports, the old No. 2 shaft is located 160 feet west of the main No. 2 shaft. However, it is not clear that this means “due” west and that it is more likely the shaft will be somewhat to the south west 160 feet of the No. 2 shaft.
6. The main problem in identifying the exact location of the mine shafts is that they have been covered over with mine rock and other materials. The only known shaft location is for the No. 4 shaft but there are two possible shafts associated with the No. 4 shaft shown in the 1882 underground mine map. Based on surface evidence near the No. 2 shaft and plotting distances from the existing underground and surface maps it appears that the sinkhole is from the ventilation shaft for the No. 4 mine. However, if the sinkhole is from the main No. 4 shaft (which I believe not to be the case), then this will move the location of the main No. 2 shaft possibly directly in to the center line of the proposed highway. Therefore, exploration digging should be conducted to identify the location of both the old No. 2 and the main No. 2 shafts. Figures 4 and 5 show the estimated locations of the No. 2 shafts based on whether the 2007 sinkhole formed in the No. 4 shaft or in a ventilation shaft further west.
7. Due to the close proximity of the old No. 2A shaft near the proposed highway, this shaft will most likely require a concrete cap. Since black powder was used to fragment the rock, the rock forming the collar of the shaft should be in good condition to support the concrete cap.
8. The mine location information provided in the Commissioner of Mineral Statistics reports investigated for this research was very consistent with the 1882 underground mine map. In fact, most of the distances quoted in these reports

were verified to within five to ten feet on the underground map. Consequently, the depth and location of the old No. 2 shaft as shown on the mine maps should be relatively reliable. The collar elevation of the shaft itself is most likely a few feet above the water table and should be about 8' by 14', which were the dimensions quoted for the main shafts at the Michigamme Mine. It is unlikely that the shaft dimensions would be much different or much larger. According to the reports the old No. 2 shaft was constructed with a derrick<sup>1</sup>. The "Practical Shaft Sinking" book of 1910 indicates that the shaft opening size was typically around 12 feet by 12 feet.

9. According to Carter and Miller, (1996) paper titled "Some observations on the time dependency of collapse of surface crown pillars" a survey of crown pillar failures in hard rock mines shows that most failures occur within 80 to 100 years of mining. They also plot the "scaled-crown" dimensions of both collapsed and stable crown pillars with respect to the Rock Mass Rating (RMR) values of the mines. An estimate of the RMR for the Michigamme Mine and its scaled span indicate that it is stable. Additional analysis using the CPillar program (Crown Pillar stability analysis program) indicated that the Michigamme mines are highly stable in the region of the highway relocation.

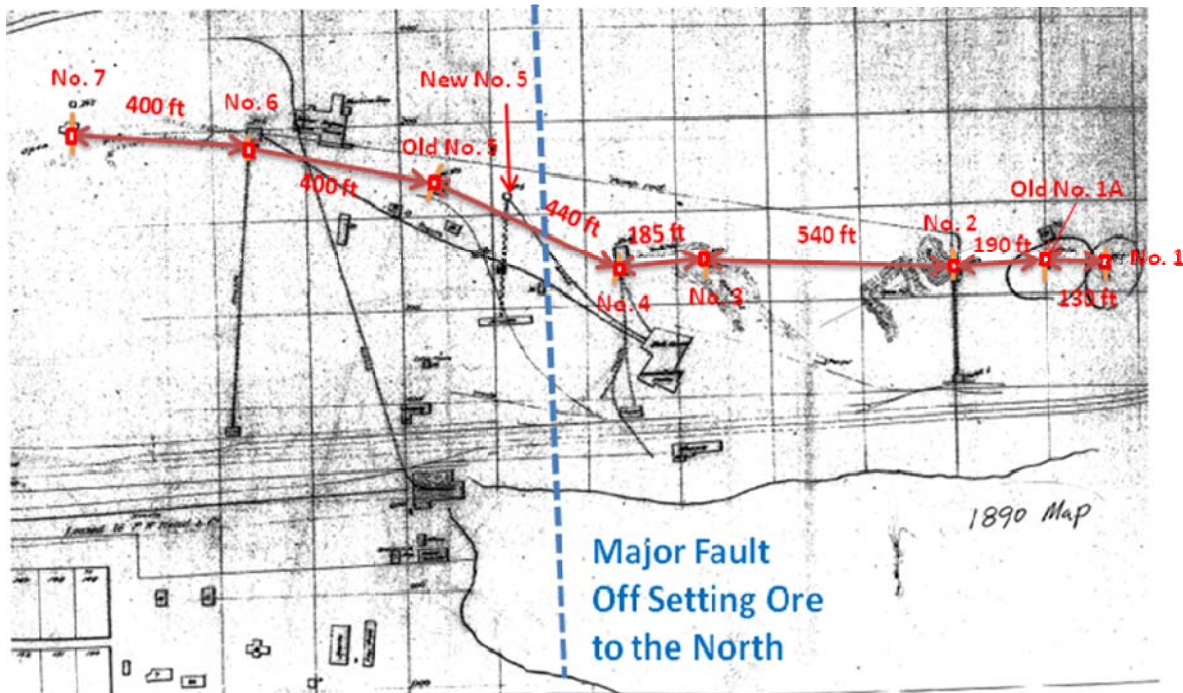


Figure 2 1890 Michigamme Mine layout with distances noted between mine shafts.

<sup>1</sup> A derrick is a short term exploration shaft head frame. It is only used either for exploration or to develop a shaft down to about 100 feet.

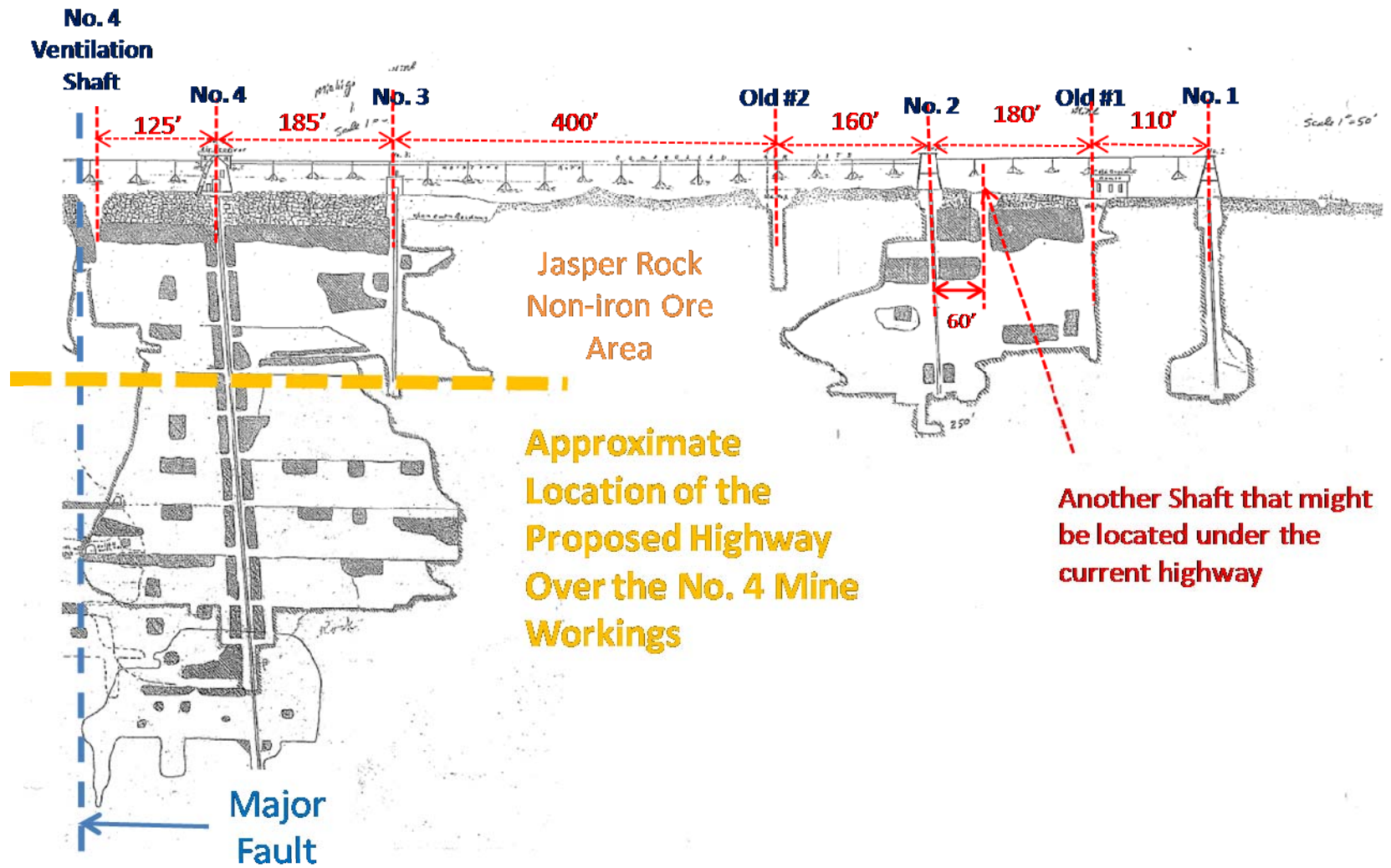


Figure 3 1882 Michigamme Mine underground mine map.

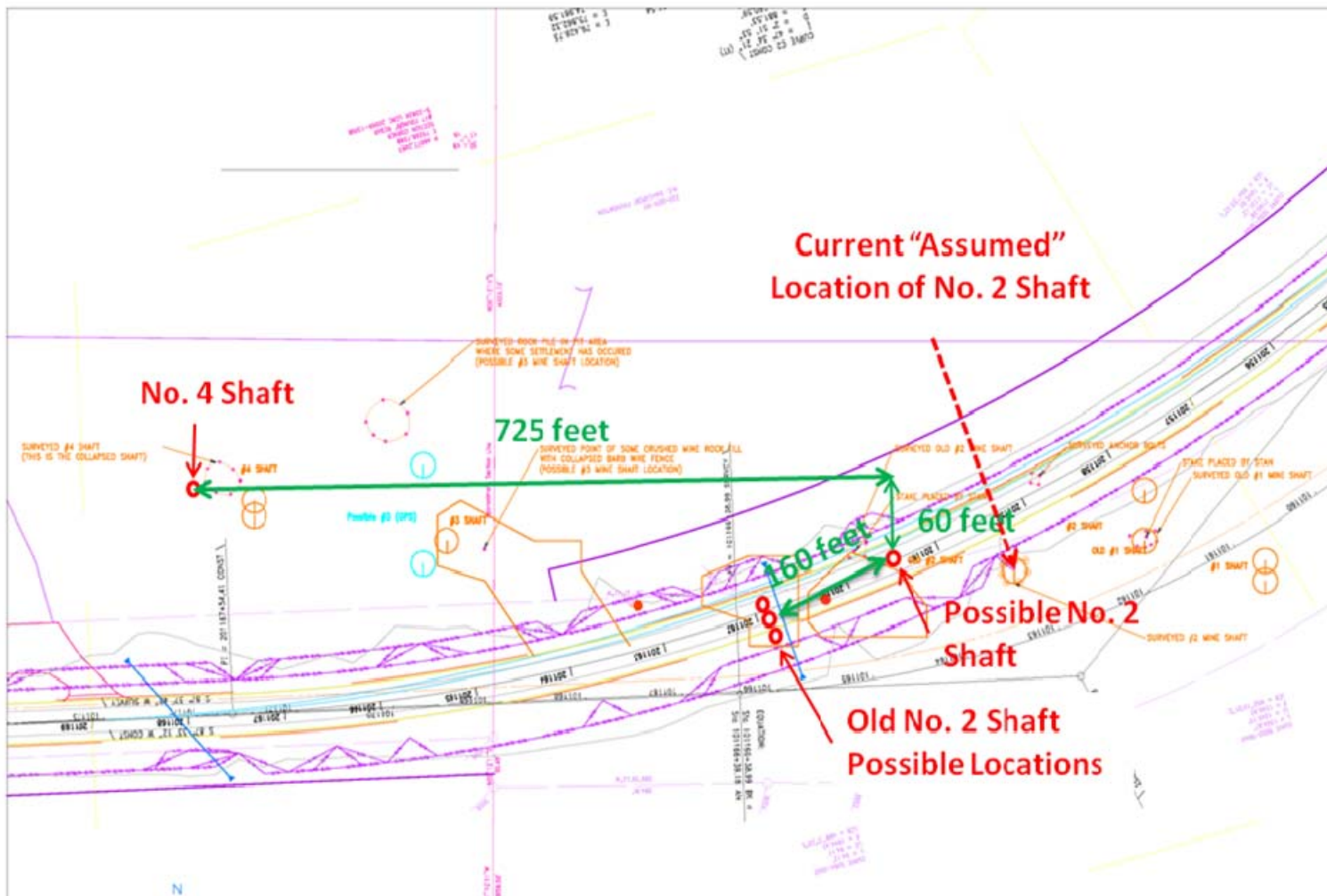


Figure 4 Estimated locations of the old No. 2 and main No. 2 shafts based on the spring 2007 sinkhole identifying the No. 4 shaft



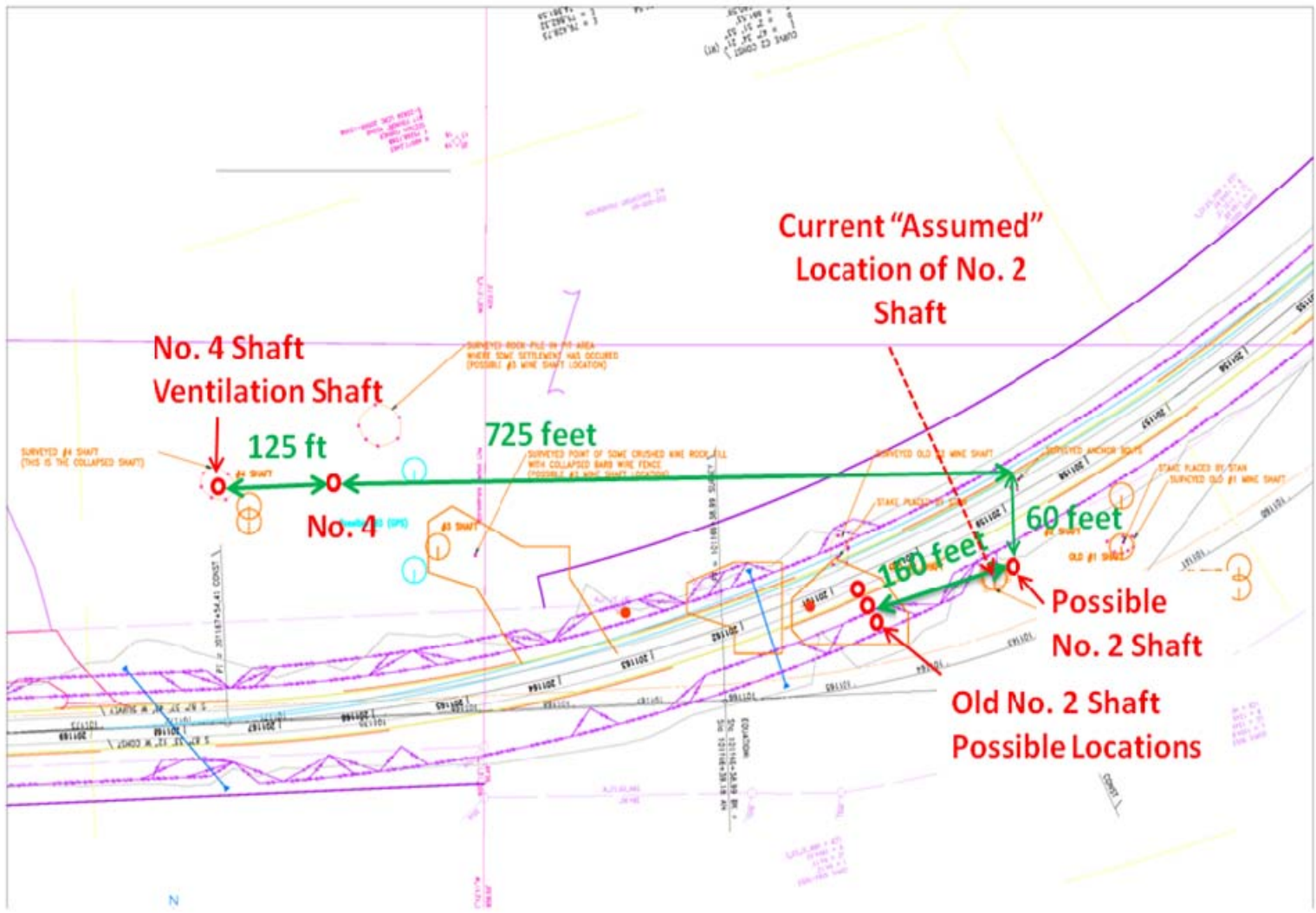


Figure 5 Estimated locations of the old No. 2 and main No. 2 shafts based on the 2007 sinkhole being the No. 4 ventilation shaft.

## SITE GEOLOGY

The Michigamme Mine is located on the north shore of Lake Michigamme in Marquette County in Section 19 and 20 Township 48 North, Range 30 West. The mine is part of the Marquette Mineral District with the principle rock units being Precambrian in age and structurally assigned to the Southern Province of the Canadian Shield. The Marquette Mineral District is developed in a thick highly metamorphosed sedimentary basin, also known as the Marquette synclinorium, in which the majority of iron ore is located in the Negaunee Iron Formation, a member of the Menominee Group in the Animikie Series. A portion of the geologic map of the Michigamme area is shown in Figure 6. The map indicates the proposed road location and the mine shafts that formed the Michigamme Mine. The Negaunee Formation is shown in the darker yellow with the Goodridge quartzite (pale yellow) and a metadiabase intrusive to the north (green). A fault separates mine shafts number 6 and 7 from the remaining shafts. However, the actual location of the fault is between the No. 4 and No. 5 shafts, which can also be seen by the “bend” in the surface mining identified on the map and the off set of the shafts themselves. The Negaunee Formation dips to the south from  $51^{\circ}$  to  $72^{\circ}$ .

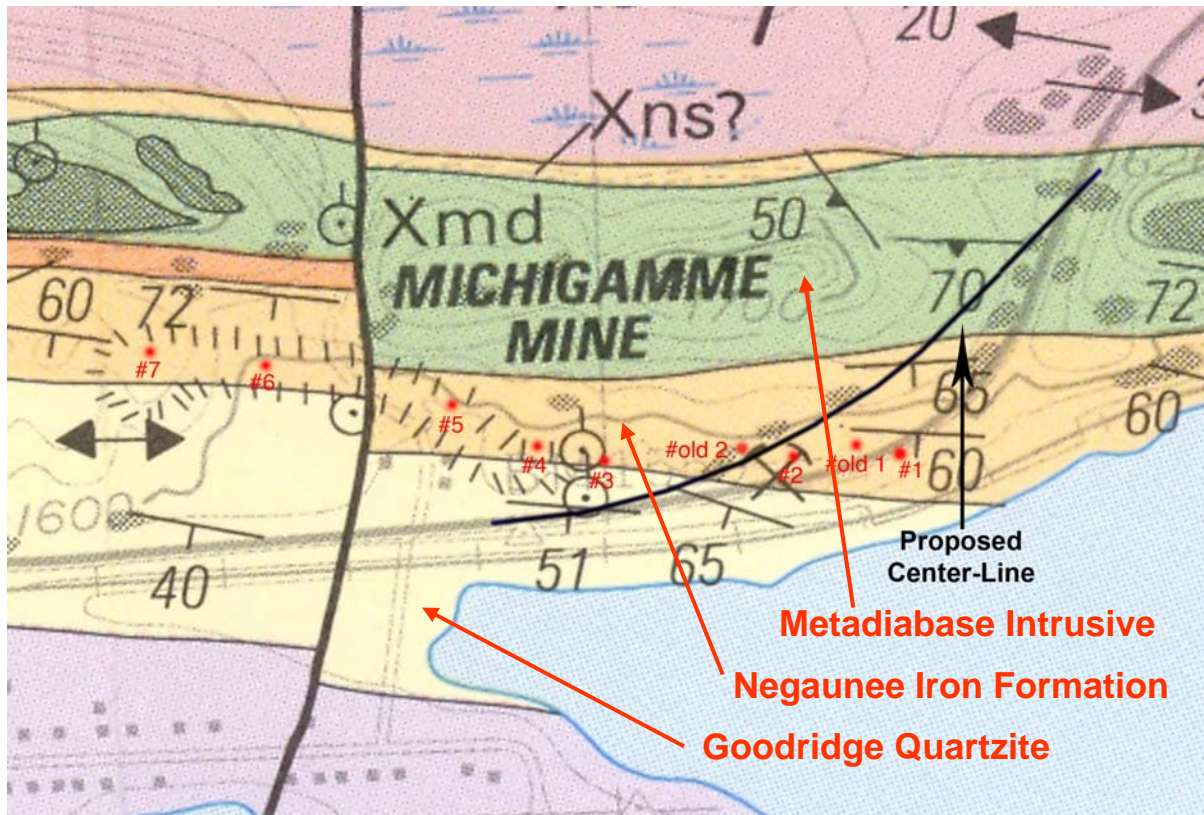


Figure 6 Geologic map of the Michigamme area.

The Marquette Mineral District contains the following four general types of ore: (1) high grade direct shipping “soft” ores, (2) high grade direct shipping “hard” ores, (3) siliceous ores, and (4) concentrates and agglomerates (pellets) from low grade iron formations. The Michigamme Mine produced direct shipping “hard” ores. These “hard” ores were generally located in the upper 200 feet of the Negaunee Iron Formation and frequently at the contact of the Goodridge Quartzite forming the hanging wall of the mine. The “hard” ores are made up of hard, compact specular hematite, and magnetite, with garnet and tourmaline as accessory minerals. The iron orebodies are frequently related to the intrusive dikes with the outlines of the orebodies frequently related to structural features such as folds, faults and dikes. The magnetite ores are commonly found in discontinuous masses in the specularitic iron-formation and ore. The discontinuous nature of the magnetite in the ore body made it difficult to mine given the limited exploration and knowledge of the deposit when the mine started operations in 1872. Although exploration using diamond drilling was utilized in the Marquette Mineral District and at the Michigamme Mine, it was limited in scope with much of the exploration work conducted during the mining operations.

### **MICHIGAMME MINE HISTORY**

A time line of the Michigamme Mine is provided in Appendix A. The Michigamme Mine was organized in the fall of 1870 with corporate offices in Chicago, IL (Northern Michigan University Archives). The officers of the company were William Barnum, president; James Rood, secretary and treasurer; and Jacob Houghton<sup>2</sup>, as superintendent. The company owned 1400 acres located at the west end of Lake Michigamme and an additional 200 acres where the town of Michigamme was located. Mine exploration started in 1870 with a number of test pits and cross cuts made across the property. Iron ore was discovered in an east-west direction over a distance of 1,600 feet at seven separate locations, which were numbered one through seven starting in the east going to the west. It was assumed at that time that the ore, which range in thickness between seven and thirty feet, was continuous at depth but at the surface it was not continuous. Prior to mining operations a 35 mile rail line called the Marquette, Houghton and Ontonagon Railroad (MH&O) was constructed from Michigamme to L’Anse and completed in 1872. The route is shown in Figure 7. To support the Michigamme Mine the villages of Michigamme and L’Anse were founded in 1871. Jacob Houghton, the chief engineer for the Houghton and Ontonagon Railroad,<sup>3</sup> platted the village of L’Anse

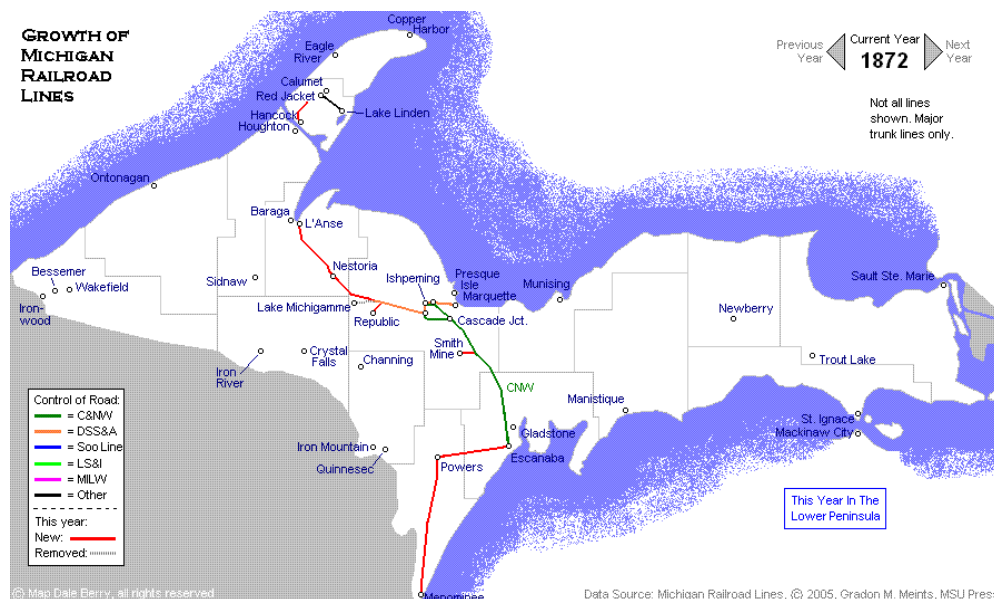
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<sup>2</sup> Jacob Houghton, was the younger brother of Douglas Houghton, the first state geologist for Michigan. It was Jacob who noticed erratic compass readings while surveying for the Government Survey Party under the direction of William Burt in 1846. His brother Douglas identified the reason for the erratic readings as being from magnetite ore bodies. The site where the erratic readings took place became the property where the Mather B Mine is located.

<sup>3</sup> In 1865 the MARQUETTE AND ONTONAGON RAILROAD COMPANY (M&O) built a line west from Windthrop Junction to Champion Junction. In 1871 the M&O bought out the Bay De Noquet and Marquette. About a year later in 1872 the M&O itself was merged into the THE MARQUETTE HOUGHTON AND ONTONAGON RAILROAD COMPANY (MH&O). The MH&O never built directly towards Ontonagon, but in 1872 they reached L’Anse from Champion Junction. In 1883 the line was extended to Houghton, and in 1888 they built west from Nestoria to Iron River, WI, on the way to Superior, WI.) In 1884 the MARQUETTE AND WESTERN built a parallel line from Marquette’s lower harbor through Ishpeming to Winthrop Mine. In 1890 the DSS&A bought the MH&O and the Marquette and

and the preliminary rail route from the eastern end of Lake Michigamme to the head of Keweenaw Bay. Houghton also oversaw the surveying for the railroad right-of-way, platting of the village of L'Anse, construction of a merchandise dock and dredging of the mouth of the Falls River to support the Michigamme Mining operations. In 1873, the ore dock was completed at L'Anse consisting of forty vessel and three steamboat pockets, with the capability to load two vessels and one steamboat at the same time. Iron ore was supplied to the dock from the Michigamme Mine and iron ore mines west of the Michigamme Mine. Plans were also made to construct a blast furnace in L'Anse but the financial panic of 1873 caused the plans to be abandoned. Overall, the ore dock in L'Anse was not successful. Ore shipments were made only on a limited basis for a few years and the dock was then idled until it was later destroyed by fire. In 1888 the Chicago & North Western Railway (C&NW) constructed a rail line to Michigamme, which allowed ore shipment to Escanaba, MI. Following the quick decline of the L'Anse dock, ore was shipped to Marquette via the MH&O line and to Escanaba via the C&NW railway for subsequent processing and shipment.

The Michigamme Mine operated from 1872 to 1901. In 1889 Mather & Co. purchased the Michigamme Mine; Mather later merged into the Cleveland Cliffs Iron Company, (CCI). Economic conditions, however, caused the mine to close in 1891. The mine ran sporadically until October 1901 when it was permanently closed, although iron ore was shipped from the mine site from existing stockpiles and from processed iron ore from waste piles through 1905. The total tonnage mined at the Michigamme Mine was 935,880 tons, with 443,247 mined from 1872 to 1881 or about 50% of the mine total. Between 1872 and 1881 the mine averaged about 50,000 tons per year, while from 1882 to the close of operations in 1905 the mine averaged about 31,000 tons per year.



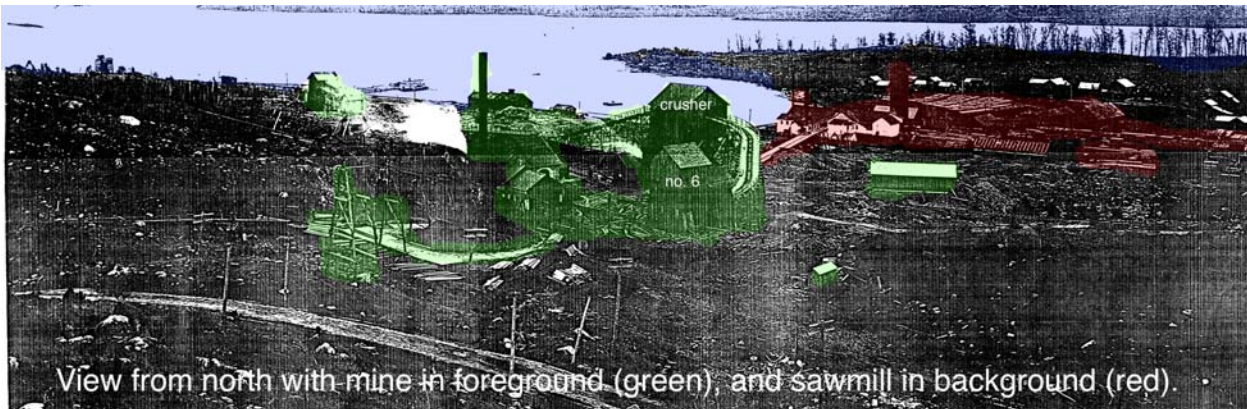
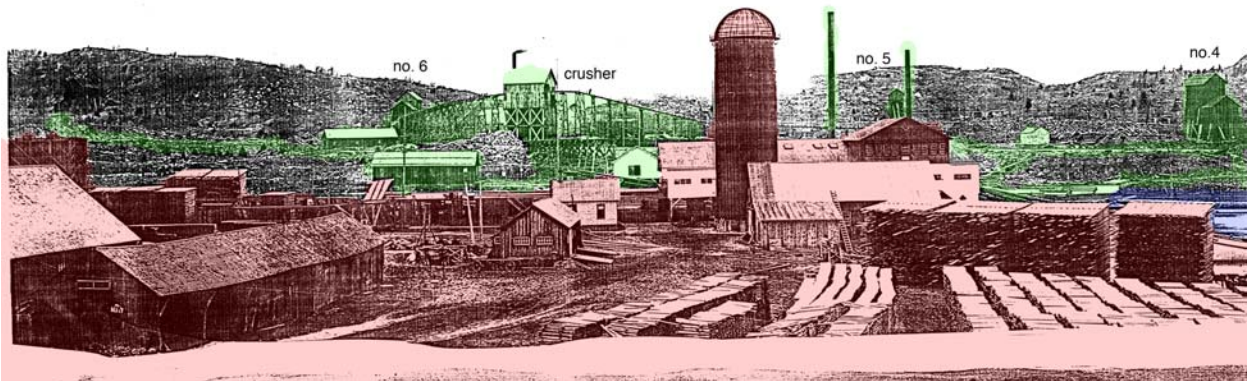
**Figure 7 Location of the MHO railroad from Michigamme to L'Anse in 1872.**

Western. Parts of the old Iron Mountain mainline and the Marquette and Western mainline were used to create the DSS&A's mainline between Winthrop Junction and Marquette.

One of the first operations of the Michigamme Mine was to construct a saw mill at the mine called the Michigamme Saw and Shingle Mill located on the west end of Michigamme Lake and on the south side of the MH&O rail tracks across from the Michigamme Mine. This saw mill later was owned by the F.W. Read & Company. A layout of the saw mill operations was obtained from the Digital Sanborn Maps<sup>4</sup>, 1867-1970. The Cleveland Cliffs Incorporated (CCI) provided a number of maps of the site as well as one photograph in 1900. The photograph was separated into two parts and is reproduced below showing a view of the Michigamme site from the south and from the north (Figure 8) showing both the mine and saw mill operations. To assist to separating the two operations the Michigamme Mine operations have been identified in green and the Michigamme Saw & Shingle Mill in a pale red.

The resources reviewed for this section are identified in Appendix B.

View from south with sawmill in foreground (red), and mine in background (green).



**Figure 8** Photograph of the Michigamme Saw Mill viewed from both the north and south.

<sup>4</sup>Michigan Technological University Sanborn Map collection. Founded in 1867 by D. A. Sanborn, the Sanborn Map Company was the primary American publisher of fire insurance maps for nearly 100 years.

## MINE OPERATIONS

As noted above, exploration of the mine property resulted in mining of seven open pits number one through seven from the east to the west side of the property. The open pits were mined by running an adit level along the vein a few feet above drainage, which would be the lowest point in the pit where the ore was delivered to a rail system. After mining about 10,000 tons of ore in the No. 1 and 2 pits work was abandoned at these pits since the ore was found to lie in alternate layers while the ore west of the No. 3 pit and beyond the No. 7 were in relatively solid ore. After depleting the ore in the open pits, Jacob Houghton then decided to mine exclusively with underground mining. The first mine shafts constructed were the No. 5, 6, and 7 to a depth of 100 feet with 25 feet of rock left as a crown pillar. The No. 4 shaft was constructed in 1875. According to Swineford (1877) in 1877 there were only four shafts that penetrated the ore with dimensions 8 ft by 14 ft. The shafts were constructed in the ore adjacent to the hanging wall (Goodridge Quartzite) with the ore left as the footwall. The primary mine plan was to open up an underground mine 1600 feet in length across the ore body with the main production between the No. 4 and 7 shaft working to depth and exploring to the east and west with production drifting. Underground mining was conducted using underhand stopes from the top and the ore falling to the bottom where it was trammed and hoisted out through the shafts. The height of the stopes was between 60 and 75 feet.

The shafts houses were located on the top of the north side of the open pit as shown in Figure 9. This would allow the skips to be lowered along the footwall of the mine. Unfortunately, the footwall was not always sloping at a consistent slope and the shafts were relatively crooked which caused significant problems with hoisting the ore out of the mines. The Michigamme Mine had seven shafts. These shafts are shown in Figure 1.



*Part of Toway Mine (MSL 6.39.49) Looking East May 1876*

**Figure 9** Photograph of an old iron mine showing the head frame at the top of the open pit.

Most of the ore mined in the area was hard high grade shipping ore. However, in the 1880's several attempts were made to use concentrating plants. Thomas Edison built a magnetic separator at the Humbolt and Spur Mines (west and south of the Michigamme Mine) in 1888, which produced 8,932 tons of high grade concentrate until the plant burned in 1889. In 1889, John Fowle, the mine superintendent of the Michigamme Mine purchased a magnetic separator system from Sweden. However, neither Edison nor the systems used at the Michigamme Mine were successful.

In the spring of 2007 a sinkhole formed near the No. 4 shaft shown in Figure 10. It was believed at first that this was the No. 4 shaft. However, later analysis indicated that it was more likely a ventilation shaft for the No. 4 mine 125 feet to the west of the main No. 4 shaft. The location of this "shaft" is important in location or determining a better location for the shafts located near the proposed highway since it is the only identifiable location for a shaft with the exception of the No. 6 and 7 shaft which are still opened.



**Figure 10 Spring 2007 sinkhole in the vicinity of the No. 4 shaft.**

## GEOTECHNICAL ANALYSIS

Three boreholes were drilled on the site and the cores taken from the holes examined. All data for estimating Rock Mass Rating (RMR) and Rock Quality Designation (RQD) were obtained from these three boreholes. It should also be noted that though the uniaxial compressive test shows an approximate value of 15 ksi, the intact rock strength is likely between 20 and 30 ksi. The lower results may be due to drilling technique.

Results of the investigation are as follows:

1. The cores from the drilling operation were obtained from the drilling crew and transported to Michigan Tech's campus.
2. The cores were photographed and stored in Dillman Hall basement lab B010A.
3. RQD measurements were taken on the sample and it varied widely between 20% and 80%.
4. Uniaxial compressive tests have been completed on the cores and an average strength of 15 ksi has been determined. The results of these tests can be found in following Appendix C.
5. Point load tests were attempted on the cores; however, the rock was too brittle to allow proper testing. Localized crushing occurred before the tests could be completed.
6. A Rock Mass Rating (RMR) has been estimated for the Michigamme crown pillars of approximately 74.

## STABILITY ANALYSIS

The primary tool used for stability analysis was the scaled span method and the *CPillar* program. Both methods required that a number of assumptions be made. First, it was assumed that the rock cored was the rock that overlaid the mine works. Second, since horizontal forces of the rock could not be measured in-situ, estimates had to be used based on common estimates. Lastly, since no full schematics of the mine were found, many geometric assumptions had to be made. Using these assumptions the following was found:

1. A "rough" model of the Michigamme mine has been developed based on the existing mine maps and understanding of the mining method in the late 1880's. This has provided an estimate of the rock structure between the mine workings and the surface.
2. The sites geologic information and RMR values have been used in the *CPillar* program to estimate the stability of the Michigamme crown pillars. In addition, the scaled span method has also been considered in the analysis. Several scenarios were developed and analyzed. The results show a very high factor of safety for the hanging wall of the Michigamme Mine in the vicinity of the highway relocation.



3. According to Carter and Miller, (1996- Some observations on the time dependency of collapse of surface crown pillars) a survey of crown pillar failures in hard rock mines shows that most failures occur within 80 to 100 years of mining. They also plot the “scaled-crown” dimensions of both collapsed and stable crown pillars with respect to the RMR values of the mines. An estimate of the RMR for the Michigamme Mine and its estimated crown scaled span indicate that it is stable. Additional analysis using the CPillar program (Crown Pillar stability analysis program) also indicated that the Michigamme mines are highly stable in the region of the highway relocation.

## **FUTURE MINING POTENTIAL**

The potential for future mining at the site or in the vicinity of the site is highly unlikely. The previous owners of the site, Cleveland Cliffs, Inc, (CCI), has conducted significant exploration activities in both the immediate and adjacent areas and have since sold the lands containing the Michigamme Mine to private interests.

The site does have some mineral collection potential for examples of chloritized garnets. According to George Robinson (2007), Curator of the Seaman Mineral Museum at Michigan Tech, “the garnets are of low to moderate value to most mineral collectors and probably of greatest interest to regional collectors who specialize in Michigan minerals, though they are certainly well-known to others.” Demark (2000) describes the mineral potential of the Michigamme Mine as follows:

“Michigamme Mine--Michigamme, 1872-1905: Located behind the Mount Shasta restaurant on U.S. Highway 41 in Michigamme, this mine is easily accessible, although collecting is not allowed. On my last visit, the sign saying "trespassers will be prosecuted" had been mangled and was lying along the knocked-down fence. Chloritized garnet is the primary collectible mineral here. Dodecahedral garnets up to 7.5 cm across occur as porphyroblasts in a chlorite schist. The outer portion of the garnets (almandine) is altered to clinocllore, and small (1-2 mm) octahedral crystals of magnetite and martite occur in the schist. This mine is also well known for attractive stellate sprays of acicular grunerite that varies from silver-gray to slightly greenish in color.”

## **CONCLUSIONS AND RECOMMENDATIONS**

The Michigamme mine is an old mine site, so surprises should not be unexpected when working in this area. However, every attempt has been made to identify the location and extent of the underground mine workings to reduce the likelihood of encountering unexpected problems. Due to the age and natural vegetation of the site, not all mine related structures (mostly foundation systems) can be seen. Therefore, it is probable that

surface foundation systems affiliated with the mine are still present and may pose some hazard to construction on this site. The following conclusions and recommendations are based only on the evidence summarized in this report and may not be valid for situations that differ from the current situation, or where further evidence has been gathered which may nullify the assumptions made in this report;

Based on the findings of this report it would appear that the mine shafts are in stable condition. If any subsidence or failure were to occur it would likely happen in a localized area around one of the larger mine shafts, which would not be of major concern to the project. Though the location of these shafts cannot be guaranteed, the locations that were marked are the most probable and based on these locations there would only be one shaft that would be within the roadway. Since this shaft is likely a small exploratory shaft it would likely not experience any subsidence. Furthermore, the section underlain by the mine is in a section which will be filled, blasting will take place farther east away from the mine. Given the small size of the blasts required, the distance from the mine site, the stability of the mine, and the strength of the rock involved it is recommended that no extra precautions be taken on this project outside of those normally taken on a site with possibly unstable areas. These precautions might include ensuring that no personnel or equipment are on or near shafts when blasting, checking the condition of shafts after blasting and possibly seismic monitoring during blasting to ensure peak particle velocities are not extreme and to detect any secondary seismic events that may signal a collapse inside the mine. Since the mine has been relatively stable for so long it is unlikely that settlement will occur, however, by filling the shafts after any subsidence should be sufficient for the continued stability of the area outside of the highway realignment.

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## APPENDIX A

### MICHIGAMME MINE TIME LINE

## Michigamme Mine Time Line

- 1870 The Michigamme Mining Company was organized 1870. The company's corporate offices were located in Chicago, IL.
- 1871 Construction was started on a railroad from the Michigamme Mine to L'Anse Bay (now the village of L'Anse). Jacob Houghton (brother of Douglas Houghton) was in charge of layout and construction of the railroad as well as the platting of the village of L'Anse. He became mine superintendent of the Michigamme Mine.
- 1872 A saw mill was constructed to provide lumber for construction of the mine and the village of Michigamme. The saw mill was located along the shore line of Lake Michigamme where the baseball fields are now located adjacent the railroad tracks. The saw mill later became the F.W. Read & Company Saw Mill. Within 1872 the village grew rapidly to a population of nearly 1,400. Surface mining started late in the year with 141 tons mined.
- 1873 The railroad and dock facilities in L'Anse were completed in 1873. That year 29,107 tons of ore were shipped out of L'Anse dock facilities. At least one blast furnace was planned at L'Anse. However, the Panic of 1873 caused furnace plans to be abandoned. Ore shipments continued in a limited capacity for a few years until the dock was idled, and later destroyed by fire.

The total tonnage mined in 1873 was 29,380 tons.

- 1874 Underground mining at the Michigamme Mine started in 1874. The first three shafts sunk were the Nos. 5, 6 and 7. It appears that the No. 4 shaft was constructed sometime in 1875. The shafts were reported to have openings of 8 foot by 14 foot. The mine left a "back" 25 feet thick of rock between the shaft and the top of the first stope.

The shafts were started at the "adit level," which was approximately 50 to 90 feet below the ground surface to where surface mining stopped just above the water table. Much of the iron ore, especially in the Nos. 6 and 7 pits, was located at the contact of the Goodridge Quartzite, which was dipping at about 60° to the south. The ore varied in thickness being very thin, ten feet or less, in the Nos. 6 and 7 pits upwards to 40 feet in the No. 4 shaft.

- 1876 Mining operations were conducted mainly from the Nos. 4, 5 and 6 shafts while only limited mining was conducted from the No.7 shaft. It was noted in the report that surface mining was still being conducted at convenient spots along the vein (pits 1 through 7). The mine's rail system at this point extended from 200 feet west of the No. 7

shaft eastward past each of the mine shafts No. 4, 5, 6 and 7 downgrade through the No. 3 pit to the main line MH&O railroad. The rail haulage system was constructed in the "adit level," which was the lowest point in the surface mine.

Approximately 10,000 tons of ore was mined from the Nos. 1 and No. 2 pits during and prior to 1876. According to Swineford (1876), the ore in the Number's 1 and 2 pits consisted of alternating layers of ore and rock, whereas the ore to the west was almost pure ore with the thickness of the ore averaging not less than 20 feet and bounded by a masses gray quartzite hanging wall to the south and ferruginous or magnetic schist to the north. However, this statement is later contradicted by the Commissioner of Mineral Statistics report who states that the ore in the No. 1 and 2 mines was irregular and thin.

The mining plan at this time was to develop the No. 1 and 2 areas by mining underground from the No. 3 shaft eastward. The same plan was considered for mining the ore west of the No. 7 mine.

By 1876 there were four mine shafts (No. 4, 5, 6 and 7) in operation. The underground mining consisted of mining drifts at intervals of 60 feet in an east-west direction away from the shaft and then stoping between the levels. Stopes were planned to be approximately 60 to 75 feet in height, working away from the shaft. However, the underground mine map indicated that the height of the stopes varied between 25 feet and 100 feet. The stopes were mined at an angle of about 60°. According to Swineford (1976) this was a new way of mining and it minimized or eliminated much of the "poor" rock produced from development work.

The water from the mine was lifted out using steam pumps placed in each shaft instead of the usual practice of one large steam pump placed in the mine. A large steam pump from the S.F. Hodge Iron Works in Detroit Michigan was purchased and constructed on the top of the hill between the No. 5 and the No. 6 mine shafts. The foundation for this steam pump is still visible along the snowmobile trail behind Mt. Shasta. The steam pump was also used to hoist the ore out of the mine. The estimated production rate for this steam engine was 800 to 1,200 tons per day.

1877-78            According to the Michigan Commissioner of Mineral Statistics Report 19887-88 the No. 2 pit, was an open pit mine 70 feet deep, and 35 feet long by 20 feet wide at the bottom. However, it appears that the No. 2 mine shaft was constructed during this period. The report states "A drift was started 40 feet above the lower level on the west side of the pit and driven 75 feet west on the hanging wall side."

The ore was hoisted out of the shaft using a derrick (not a shaft house) operated by a small friction engine. According to a book on shaft sinking "Practical Shaft Sinking" (F. Donaldson, 1910)

*"For sinking a shaft through the surface soil, a small stiff-leg derrick is usually erected. This makes excavation and timbering cheaper than is done by hand, and it does not interfere with placing the surface concrete or add weight to the ground around the shaft. A derrick with a 40 ft. boom and a 30 foot mast, built 12 x 12 in timber, is large enough for sinking. It can be readily swung by two men at the end of a 10 foot lever bolted to the mast. "*

The book further states that

*"Although a small shaft may be readily sunk with a derrick for 200 feet, it is better to put up a head frame when the surface timbering and masonry is completed."*

At this point in time the No. 4 shaft was developed down to the third level approximately 150 feet below the adit level, while development work was being conducted down to the fourth level.

No. 5 shaft was located 440 feet west of the No. 4 shaft and developed to a depth of 160 feet down to the third level of the mine. Everything above the second level was mined out between the No. 5 mine and the No. 6 mine. According to the Commissioner of Mineral Statistics report *"nothing remained above the second level, between this shaft and the No. 6 shaft, except the supporting pillars and a pyramid of mixed ore situated midway between the shafts"*.

The No. 6 shaft is located 400 feet west of the No. 5 shaft. The adit level is 70 feet below the surface. The mine was developed to a depth of 165 feet below the adit level. The ore below the adit level has been mined to a depth of 90 feet in the No. 5 shaft and 175 feet west towards the No. 7 shaft. It is unclear as to whether this 90 foot level was mined underground or whether the adit has also been mined out. It would appear from the appearance of the site today that this 90 foot level was mined underground.

The No. 7 shaft is developed 75 feet below the adit.



Through 1877 the mine produced 217,393 tons of ore. The majority of this ore came from the Nos. 1 and 4 shafts.

- 1880 The iron ore in the west portion of the mine in the Nos. 5, 6 and 7 shafts was found to be relatively thin and erratic with the quartzite hanging wall cutting into the ore. Consequently, mining west of the No. 4 shaft was abandoned. Instead, development work was concentrated between the No. 4 shaft and the Barnum Shaft (No.1 shaft), a distance of about 800 feet. The No. 3 shaft was developed down to the fifth level of the No. 4 shaft to assist in haulage of the ore in the No. 4 mine and to mine eastward to the No. 2 shaft. At this point the No. 2 shaft was developed down to 200 feet. The No. 3 mine was also planned to be a hoisting shaft when mine started eastward. However, it was later found that a significant amount of jasper rock lay between the No. 3 shaft and the No. 2 shaft. This is the large outcrop of rock that exists between these two mine areas and is adjacent to the old No. 2 shaft that is located near the proposed highway alignment.

Mining to the west in the No. 4 mine encountered a major fault that cut off the entire ore body. This fault can be seen on the USGS geologic maps of the area and is the reason for the northward off-set in the east-west alignment of the mines. Every level of the No. 4 shaft hit this fault while working west.

The No. 1 shaft was sunk at an angle of 60° through nonbearing (chloritized schist) rock to a depth of 138 feet where the shaft hit the ore. According to the Commissioner of Mineral Statistics report the ore was located north of the quartzite hanging wall and that a drift needed to be driven south to the hanging wall where a shaft would be developed along the hanging wall. Diamond drilling was used to delineate the ore body in the No. 1 shaft.

Through 1880 the mine produced 385,975 tons of ore.

- 1881 Significant exploration using diamond drilling was conducted in which they discovered a fault that had “thrown” the iron ore to the north. A drift was excavated from the No. 4 shaft towards the ore beyond the fault to the north.

The rock in the No. 1 shaft was found to be “broken up” and they were unable to find a stable quartzite hanging wall. The ore was also found in small irregular pockets.

In 1881 the No. 2 pit was “looking good”. The main problem with the No. 2 pit was similar to the No. 1 pit and shaft in that there was no “true” hanging wall. This apparently caused stability problems in the underground mining operations. This also explains the large amount of chloritic schist located in the rock piles around the No. 2

shaft, i.e., they had to mine through the chloritized schist to get to the irregular iron ore bodies.

At this point approximately two-thirds of the ore mined was from the No. 4 shaft. The ore production through 1881 was 443,274 tons.

- 1882 Diamond drilling through the fault in the No. 4 shaft located ore about 220 feet to the west north-west on the 5<sup>th</sup> level. The ore was dipping at 62° and was about 27 feet thick. A second drift was made from the 4<sup>th</sup> level west through the fault to the ore. It appears that these drifts are indicated on the 1882 underground mine map.

Mining east of the No. 3 shaft hit non-ore bearing rock (Jasper) and mining was stopped.

The No. 2 shaft is located 575 feet east of the No. 3 shaft. Prior to 1882 no mining was conducted between the No. 2 and No. 3 shafts. However, in 1882 the mine shaft was sunk 160 feet west of the No. 2 shaft to a depth of 80 feet. This is the shaft closest to the proposed highway alignment. It appears that this shaft did not encounter any ore and in fact mining in the No. 2 shaft below this depth (see 1882 Mine map) hit a large formation of Jasper rock while mining westward. It appears from the reports that the ore in the No. 2 was very difficult to mine and that *"unless an ore body of sufficient size was encountered there would only limited mining in the No. 2."* From the reports it appears that little mining was conducted from the No. 2 shaft after 1882. At some time prior to 1882, the No. 2 shaft did mine east to the old No. 1 shaft. In 1882 they were filling in the Old No. 1 shaft with rock and according to the Commissioner of Mineral Statistics report it was *"pretty well filled up with rock."*

According to the reports the Nos. 1 shaft, 278 feet east of the No. 2 had significant potential but was a disappointment and was not further mined.

A new shaft between the No. 4 and 5 shafts was constructed, which is shown on the 1882 underground mine map. The original No. 5 shaft is now called the "old No. 5 shaft" and the new shaft the "No. 5 shaft". The development work for this shaft can be seen on the 1882 underground mining map.

Through 1882, 486,721 tons of ore had been mined.

- 1886 An economic depression in the early and mid-1880's limited the mining at the mine especially in 1884 where only 12,372 tons of ore were mined.

According to the 1886 report *"The mine has never come up to expectations that were entertained regarding it at the time it was first opened. The deposits of ore have proven*

*to be of limited extent – too short and too narrow, and in some of the stopes and pits the ore is not clean enough, i.e., not fully free from rock. It, in such cases, requires a good deal of sorting, picking over, which adds to the cost. The ore in the No. 4 shaft, a medium grained magnetic of superior quality, being very clean, high iron and low in phosphorous. But in the other shafts, No. 5 and No. 3, the ore contains a mixture of actinolite and hornblende, which renders it objectionable to furnaceman.”*

Only the No. 4 and No. 5 shafts were being worked in 1886. The tonnage mined through 1886 was 569,188 tons.

The Michigamme Mine was acquired by the Mather & Co., which later merged into the Cleveland Cliffs Iron Company (CCI).

1887 Mining in the No. 4 and No. 5 shafts was at the same depth as they were in 1886 and neither mine was producing “good” ore. At this point the mine management started to pay out dividends instead of continued investment in the mine, e.g., further exploration drilling. According to the Commissioner of Mineral Statistics report, the No. 4 shaft was at exhaustion.

Most of the mining was from the No. 5 shaft and some new mining below the long abandoned No. 6 shaft. Since the No. 6 shaft was not developed at this depth, ore was hauled over to the No. 5 shaft, which apparently resulted in lower productivity. There were plans to develop the No. 6 shaft for hoisting the ore out of the mine instead of hauling it over to the No. 5 shaft for hoisting.

The tonnage mined through 1887 was 618,103 tons.

1888 In 1888, there were improvements in the mine. At this point in time all of the ore was being mined from below the No. 6 shaft and hoisted out of the No. 5 shaft. According to the Commissioner of Mineral Statistics report *“the new ground which is yielding well.”* The ore, which at a depth of 450 feet, *“is 14 feet wide and entirely clean.”* In regard to mine stability, *“The hanging wall is smooth and sustains itself well.”* The dip of the ore body is at 50°. The iron ore was analyzed and found to be between 65 and 68% iron. The ore production in 1889 was stated to be the best ore mined in the past ten years.

The mine is considering re-developing the No. 6 shaft to eliminate the long tram (haulage) to the No. 5 shaft.

Exploration drilling at the bottom of the No. 4 shaft shows improved ore at depth. The No. 4 shaft was extended down to a depth of 750 feet.

Due to the positive outlook of the mine, exploration was conducted in both the No. 3 and No. 2. shafts. The No. 3 shaft was being sunk deeper. Some ore was mined out of the No. 3 shaft during the summer of 1889.

The No. 2 shaft was sunk an additional 40 feet but the ore pinched out.

Ore mined through 1888 was 654,551 tons.

1889 A magnetic separator from Sweden was utilized at the mine. The separator was a Venstrom Magnetic Ore Separator. It was a rival of the unit Thomas Edison introduced at the Spur and Humbolt Mines. One reason for the introduction of this separator was the large amount of waste piles stockpiles at the mine contain rock and iron ore. Three units were purchased and made operational at the mine with a capacity of 600 tons per day. According to the report the units were very successful.

The (old) No. 6 shaft was reopened and extended downward to the working stopes now developed below the No. 6 shaft.

The mine was purchased by the Cleveland Cliffs Iron Mining Company. They hoped to raise the mine's production to 100,000 tons per year.

Ore production through 1889 was 711,550 tons. However, this tonnage is not consistent with the Michigan Commissioner of Mineral Statistics report for this year.

1890 In 1890, more than 80,000 tons of ore were produced.

1891 Due to an economic depression in 1891 the Michigamme Mine was closed and allowed to fill with water although the magnetic separators were kept in operation.

1892 The magnetic separators were discontinued and the mine closed. 1,894 tons of ore were produced in 1892.

1895 The mine remained closed.

1897 The Commissioner of Mineral Statistics report state that the "hard ore mines", of which the Michigamme is one, have been in operation by removing pillars. It is not clear whether this has occurred at the Michigamme Mine or not. It would be unlikely that pillar robbing took place in the Michigamme Mine since most of the mining was conducted in stopes with the majority of the pillars used to support the main hoisting shafts.

1898 Mine remained idle.

1899 The Michigamme Mine was re-opened in late 1899 by CCI. A note was made that the share holders of the Michigamme Mine were also the share holders of CCI. Also noted was that the magnetic separators used in early 1890's were in fact not successful. The mine took many months to dewater and was now at a depth of about 1,000 feet.

Prior to 1899 it was estimated that the Michigamme Mine produced 880,662 tons of ore.

Mining was planned for the No. 4 to No. 7 mines with the Nos. 1 and 2 considered to be mined out. The mine equipment was updated and overhauled.

The distance between the mine shafts was given as:

No. 1 to No. 2	278 feet	
No. 2 to No. 3	575 feet	
No. 3 to No. 4	196 feet	
No. 4 to No. 5	400 feet	Note: this must be Old No. 5
No. 5 to No. 6	400 feet	
No. 6 to No. 7	400 feet	

Mining was conducted in the No. 6 and No. 4 shafts. The depths of the mines were given as: No. shaft 4 at a 1,000 feet, No. 5 shaft at 750 feet, No. 6 at 800 feet, and the No. 7 at 100 feet.

The Nos. 6 and 4 shafts were connected at the tenth level.

The mine was found to be in good shape although it had been underwater for ten years. The mine was not considered a wet mine although it is adjacent and under Lake Michigamme and had good ventilation.

*According to the report "No. 1 shaft was filled with waste rock nearly 15 years ago and it is unlikely that No. 2 shaft shall be used again."*

1900 The mine was in production through 1900.

1901 The Michigamme Mine was closed and abandoned in October 1901. The total production from the mine was 935,880 tons, although some reports show the mine only producing 880,362 tons and operating until 1905, which might have been from ore shipment from existing ore stockpiles.

APPENDIX B

RESOURCES

&

NORTHERN MICHIGAN UNIVERSITY AND  
CENTRAL UPPER PENINSULA ARCHIVES

The following records were used in the analysis of the mine:

1. Dr. Terry Reynolds of the Social Sciences Department at Michigan Technological University provided a list of records on the Michigamme Mine at the Northern Michigan University Archives. This list is provided at the end of this report. A trip was made to inspect these records and other materials on the Michigamme Mine. Almost all of the records at Northern Michigan were financial and/or daily correspondence between the mine and the corporate offices in Chicago, IL. No maps were found that provided the full extent of mining. The mine started production in 1872 and the first year of records existing at the library were for 1875. I read through most of this correspondence. It appears that the mine was still in the development mode and attempting to develop their underground works. It was very difficult to determine from this correspondence which mine was under development in 1875.
2. According to Dr. Reynolds, a severe economic depression occurred in the mid-1880's into the 1890's and that most likely little mining occurred from the Michigamme Mine due to its lower quality ore and higher mining cost relative to the iron mines in the Negaunee and Ishpeming areas
3. The archives at Michigan Tech were also investigated for materials on the Michigamme Mine. However, very little information was found. There were a couple of technical articles on the processing of ore at the Michigamme Mine but no papers discussing the extent or mining methods used in the mine were found.
4. A Mr. Don Moore at the Michigamme Museum in Michigamme was contacted. This is a very small museum in Michigamme that mostly deals with the history of the Michigamme area. He indicated that they have some maps concerning the railroads in the area but they do not have any information on the Michigamme Mine itself.
5. The Michigan Iron Industry Museum in Negaunee was visited. This is a very impressive museum but they did not have any additional information on the Michigamme Mine.
6. The Iron Country Historical Museum in Caspian, MI was also contacted for information on the Michigamme Mine. While they have some mine related information for the mines in Iron County, they did not have information on the Michigamme Mine.
7. The MDOT drilling crew spoke with a Mr. John Olson, the Michigamme Township supervisor. He indicated that there had been some cave-ins at the Michigamme Mine. The Township office was contacted, but Mr. Olson has not returned any calls. Mr. Don Moore from the Michigamme Museum was asked about cave-ins and he was unaware of any with the exception of where CCI had filled in some of the abandoned mine shafts and some settlement of the fill had been experienced.
8. An extensive literature review of crown pillar stability was conducted. The crown pillar is the term used in the mining industry to describe the rock structure between the mine and the surface. It is the stability of the crown pillar that is investigated for surface stability purposes.

9. There are two manuals specifically written for the analysis of underground mines: (1) the Ontario Ministry of Mines Manual for the analysis of crown pillars and (2) a recently developed manual for investigating abandoned mines. Both manuals are being consulted concerning this analysis.
10. A walkthrough of the proposed centerline was performed in April to determine the locations of any identifiable shaft locations. The shafts located are Old #1, #2, Old #2, #3, #4, and #5. Shaft #1 is located somewhere near to or south of the current roadway.
11. Several of the shaft sites showed signs of rockfill settlement. The best example is the No. 4 mine shaft which subsided significantly this past spring (Figure 6).

MICHIGAMME MINE materials is Archives of Michigan (Northern Michigan University repository)  
MS 86-100

ID	Item #	Name of Firm	Office Name	Title of Record	Date	Format	Location
760	760	Michigamme Co.		Ore Ledger	1890-96	Volume	47/12/5
761	761	Michigamme Co.		Ore Ledger	1890-96	Volume	47/12/5
762	762	Michigamme Co.		General Ledger	1870-90	Volume	47/12/5
763	763	Michigamme Co.		General Ledger	1870-90	Volume	47/12/5
764	764	Michigamme Co.		General Ledger	1890-1912	Volume	47/12/5
765	765	Michigamme Co.		General Ledger	1912-19	Volume	47/12/5
1029	1029	Michigamme Co.		Journal	1870-90	Volume	47/13/5
1030	1030	Michigamme Co.		Journal	1890-1919	Volume	47/13/5
1194	1194	Michigamme Co.		Cash Book	1870-79	Volume	47/13/11
1195	1195	Michigamme Co.		Cash Book	1879-84	Volume	47/13/11
1196	1196	Michigamme Co.		Cash Book	1885-90	Volume	47/13/11
1197	1197	Michigamme Co.		Cash Book	1890-1919	Volume	47/13/11
2725	2725	Michigamme Co & others		Corresp.	1874-1879	Box	
2726	2726	Michigamme Co.		Corresp.	1880-1890	Box	

Bieniawski, Z.T. (1984). *Rock Mechanics Design in Mining and Tunneling*. Rotterdam: Balkema



## Appendix C

### Uniaxial Compressive Test Results

<b>BH 4</b>		
<b>Sample #</b>	<b>Stress at Failure (ksi)</b>	<b>Young's Modulus (ksi)</b>
1	9	27,400
2	1	27,300
3	19	69,400
<u>4</u>	<u>8</u>	<u>29,500</u>
Average:	9	38,400

<b>BH 5</b>		
<b>Sample #</b>	<b>Stress at Failure (ksi)</b>	<b>Young's Modulus (ksi)</b>
1	15	47,600

<b>BH 6</b>		
<b>Sample #</b>	<b>Stress at Failure (ksi)</b>	<b>Young's Modulus (ksi)</b>
1	21	48,800
2	26	47,800
<u>3</u>	<u>20</u>	<u>72,100</u>
Average:	22	56,200

