BUILDING NARRATIVES, MAPS, AND DOCUMENTATION
TORCH LAKE INDUSTRIAL WATERFRONT

PHASE 1:
From North end of Torch Lake to Hubbell Heach C&H Lake Linden
Operations Area of the
Abandoned Mining Wastes - Torch Lake non-Super Fund Project

TASK 3:
Historical Archive Research & Mapping

Prepared for:

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SECTION 1: INTRODUCTION

This document encompasses the materials collected by Michigan Technological University (MTU) Social Sciences and the Michigan Tech Research Institute (MTRI) staff in support of Phase 1, Task 3 of the Department of Environmental Quality project to study and sample "Abandoned Mining Wastes of the Torch Lake Non-Superfund Site, Contract No. Y14110."

Task 3 is devoted to the historical and archival work on C&H Torch Lake industrial facilities, and to the production of Geographic Information System (GIS) data and associated maps, which identify building locations. The December 2014 Statement of Work (SOW, Appendix A) specifies the following 8 tasks that were to be accomplished by the Social Sciences Department in order to support DEQ, Weston, and MTU in identification of on-water and on-land sampling sites for the Phase 1 area from the North End of Torch Lake (Lake Linden) southward to Hubbell Beach:

1. Identify major contaminants and waste streams of concern from industrial buildings and likely locations: PCBs (completed through Sea Grant Michigan); chemicals in reclamation processes; sludge from reclamation; slag from smelting; coal-related products such as fly-ash; leaching reagents from stamp mills and reclamation (ammonia, xanthates); others that may be identified in archives.
2. Investigate MTU and KNHP C&H archives on building function, production processes, chemical processes, and waste streams by building location.
3. Produce Building Narratives for 18 buildings (in order of location from north to south).[1] Building narratives will be prioritized according to potential to produce significant contaminated wastes to optimize information necessary for soil and sediment sampling in late spring-summer season. Narratives of buildings deemed insignificant for contaminated waste production will be brief, but included in order to document their elimination.
    a. Narratives will detail opening/closing dates; production activities within individual facilities; major updates in processes; repurposing of buildings for different production activities; information on incoming chemical, metal, or other waste and possible exit sites from buildings. Narratives will draw upon archival sources, maps, blueprints, and interviews.

[1] Building names are drawn from official names utilized by C&H and Sanborn Co. maps. Data for some buildings are largely collected through study of C&H electrical system and PCB sources.

b. 18 buildings: Houghton County Electric Light & Power (Sub-Station #9); C&H Flotation Plant; C&H Leaching Plant; C&H Regrinding Plant No. 2; C&H Regrinding Plant #1; C&H Regrinding Plant #2; Lake Linden Substation; Calumet Stamp Mill; Hecla Stamp Mill; Still House; C&H Power Plant; C&H Boiler House; Coal Dock Sub-Station; C&H Mineral House; C&H Smelting and Refining; C&H Electric Shop (in smelter); C&H Smelter Power Plant; C&H Electrolytic Plant; C&H Acid Treating Plant.

4. Collect and scan available Sanborn maps (through 1928) and C&H blueprint maps for 18 buildings listed above.
5. Conduct interviews with knowledgeable individuals about individual plant operations.[2]
6. Provide a spreadsheet of sources consulted, relevance for which waste material or chemical – e.g. C&H box and files title/# in MTU or KNHP archives.
7. Provide a bibliography of relevant sources that detail or describe significant processing methods, chemical usages, and waste collection strategies for C&H Mining Co. during period of Torch Lake operations (1880-1970).
8. Identify, if possible, the footprint for buildings identified with DEQ staff as critical for soil sampling. This to be done in collaborating with team members involved with GIS mapping for the project.

These tasks have been completed and materials are available in this document. Several graduate students in the Industrial Archaeology Graduate Program provided research assistance: Emma Schwaiger (MS student) has provided the bulk of archival and interview data. Recently, John Baeten (Ph.D. student) and Brendan Pelto (MS student) have surveyed professional journals and newspapers for accounts of C&H facilities, processes, and other news. In addition, MTRI has contributed to these tasks by geospatially referencing data sources for use in GIS systems and by providing maps of these data.

[2] Sea Grant Michigan and KNHP have funded interviews during Fall 2013 and Spring 2014 semesters. If any additional individuals are identified during the DEQ funded research, they will be interviewed.

This document is organized in the following sections:

Section 2 includes the narratives of 22 (and additional 4 sites have been added to the original 18) buildings and sites investigated by the research team. Also included are a set of Google Maps with buildings identified by location, name. Detailed chronologies for each building are provided in the Building Narratives and on the Google Maps.

Section 3 includes the GIS data and associated maps produced by MTRI. These data include GIS-ready formats of Sanborn sketches, relevant blueprints, and descriptive maps of each dataset for use in presentations and reports. These products are intended to assist Weston and the MDEQ in their investigation and presentation of findings.

Section 4 provides various background and useful resource documents. Included are articles from professional mining engineering journals that document C&H Torch Lake developments in the 1910s through 1930s. Summaries of three interviews appear here, with most pertinent information highlighted at the end of the summary. In addition we have provided a set of resources and research notes that will be helpful in reading the historical record of C&H activity along Torch Lake.

Section 2: BUILDING AND SITE NARRATIVES & CHRONOLOGIES

Phase 1: North End of Torch Lake to Hubbell Beach

2.1 - Torch Lake Phase 1 Building Narratives

This section assembles narratives with information about C&H buildings in the Lake Linden and Hubbell areas (Phase 1). Also included are a series of Google Maps with the approximate building sites identified, along with brief chronologies of major changes in processes and building design. Twenty-two building and other sites are documented utilizing sources from the C&H Collection at MTU Archives, articles from mining engineering journals, and interviews. The Building Narrative Template (next page) provides categories for information. In several cases, narrative categories are incomplete because archival sources did not yield any useful information.

The maps, blueprints, journal articles, and interview summaries referenced in the individual narratives are provided in Section 4 of this report. A bibliography of these and other useful sources is included in Section 4.

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20. C&H Acid Treating Plant
21. Jos. Ethier & Co. Lumber
22. Hubbell Garbage Dump

NARRATIVE TEMPLATE

Building Name & #____

Alternative (common) names for building:

Dates:

1. Built: _________
2. Modified (external structure)________________
3. Ceased operations: _______________________
4. Structure removed: __________________________

Maps available
(Title, date, location, information present for building)

Building Narrative:
(Descriptive history of building uses, processes, major modifications described with dates where available. Includes list of major sources of information and location)

Supporting Documents:
(Copies of articles with extensive description, scientific papers on relevant processes)

Building Timelines:
(Chronology of major changes in building activity, processes, and design)

Potential Waste/Pollution Concerns:
(Known use of chemicals in processes inside facility; major type of waste material produced; any information on disposal of waste material)

1. Houghton County Electric Light & Power (Sub-Station #9)

Significant: Yes
Alternative (common) names for building:

Dates:
1. Built: between 1890 and 1902
2. Modified (external structure):
3. Ceased operation: between 1947 and 1969
4. Structure removed: Still exists – 58340 Gregory St, Lake Linden, MI 49945, Schoolcraft Twp. Current use: storage facility.
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928, 1935.

Building narrative:

The Houghton County Electric Light & Power building was built between 1890 and 1902 when the land was owned by the Peninsula Electric Light & Power Co. which then became the Houghton County Electric Light Co. It was then sold to the Upper Peninsula Power Co. in 1947 and again to the Village of Lake Linden in 1969 when the building was probably no longer used as a sub-station. It is currently owned by Betsy Olson West of Saint Petersburg, FL.

Supporting documents:
See research report on Substation #9 – Houghton County Courthouse documentation.

Building Timeline: Houghton County Electric Light & Power (Sub-Station #9):
1890 – Property bought by Peninsula Electric Light & Power Co.
1902 – Name change to Houghton County Electric Light Co. Built sometime after 1890.
1917 - Sanborn
1928 - Sanborn
1935 – Sanborn
1947 – Sold to UPPCO
1969 – Turned over to the Village of Lake Linden
1990 – Sold to Betsy Olson West

Potential Waste/Pollution Concerns:
After extensive research, it is unclear whether this substation continued operation after the 1930s—the era when PCBs were introduced into transformers.

2. C&H Flotation Plant

Significant: Yes, not for PCBs
Alternative (common) names for building:

Dates:

1. Built: 1918
2. Modified (external structure): 1919
3. Ceased operation: 1953
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928.

Building narrative:

The Flotation Plant to treat smiles from the Regrinding Plants were in commission beginning in 1918 and by 1919 they realized they needed a larger building to complete the flotation. It closes in 1953 when the Lake Linden reclamation plant has exhausted all useable tailings.

Flotation is a process which uses xanthates and pine oil to get particular mineral particles, in this case copper, to adhere and float to the top of large vats in the form of foam and froth, which is then skimmed off and separated from the other materials and collected.

Supporting documents:
See: C. H. Benedict, "Flotation Practice at the Calumet & Hecla" (1931). Also, CH Benedict, "Six-Cent Copper from Calumet & Hecla Tailings" (1924), and CH Benedict, *Lake Superior Milling Practice,* Chapter 8, "Flotation."

Building Timeline: C&H Flotation Plant:
1916 - Oil flotation experiments underway
1917 - Flotation experiments successful
1918 - Flotation plant to treat slimes from Regrinding Plant should be in commission in summer
1919 - 2/3 of slimes from Regrinding Plant are treated by flotation, building need extending
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1953 - Tailings exhausted, closed

Potential Waste/Pollution Concerns:
Pine oils and xanthates (toxic to aquatic biota) were commonly used to float copper from the material produced by the stamp mills. With copper removed from the "frothing," it is unclear how the remaining material was treated. The archival and published record is silent on this aspect. The waste sludges would likely have other heavy metals in them.

3. C&H Leaching Plant

Significant: Yes, not for PCBs
Alternative (common) names for building:

Dates:

1. Built: 1914-1915
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:

Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928.
Army Corps of Engineers, Michigan Tech Archives: 1962, 1970.

Building narrative:

The Leaching Plant construction was started in 1914 and completed in 1915. The actual ammonia leaching began the following summer in 1916. In 1942 the following information is given from the C&H Annual Reports: "The leaching process in use on copper-bearing sands is adaptable to the recovery of copper from scrap of various kinds, including the treatment of scrap from copper and brass coated steel. C&H has successfully treated at Lake Linden leaching plant, yielding the original steel as scrap for steel mills and copper recovered as oxide which is refined at the smelter. They go through 2,500 tons of scrap metals per month."

In 1944 the leaching plant was remodeled to adapt it to the production of copper oxide from secondary copper products, but these were interior machinery and process changes to help provide the most copper possible to help with the war effort. In 1953 when the rest of the reclamation plant is closed down, the leaching plant remains open and processing. The end of the leaching plant is believed to be tied to the closing of the company in 1968.

Leaching is a process where an ammonia solution is mixed with copper bearing sands and put into large holding tanks where the ammonia dissolves the copper. This ammonia and copper solution is then separated from the rest of the material and heated. The ammonia is evaporated and recycled, whereas the copper is precipitated into copper oxide, which was then sent to the smelter to be processed into pure copper.

Supporting documents:
See C.H. Benedict, "Ammonia Leaching of Calumet Tailings" (1917); and his *Lake Superior Milling Practice* (1955). Also see his "Developments in Lake Superior Milling"

(1919), Chapter 9 on "Leaching:" and his"Milling at the Calumet & Hecla Consolidated Copper Company" (1931).

Building Timeline: C&H Leaching Plant:
1914 - Ground broke for new Leaching Plant
1915 - Building complete, ammonia
1916 - Processing began in July
1917 - Sanborn
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1942 - Leaching process in use on scrap from copper and brass coated steel
1953 - Rest of Reclamation Plant closed, Leaching still in operation

Potential Waste/Pollution Concerns:
Ammonia was the primary chemical utilized in leaching copper from material produced by stamp mills and in later years, tailings and scrap metals (recovery from secondary products). Benedict claims in *Lake Superior Milling,* that the ammonia was continuously recycled in the leaching process. A common waste material from leaching (and flotation) was a finer stamps and material that was re-deposited into Torch Lake in the vicinity of older stamp sand piles. The leaching process was regularly applied to reclaimed stamp sands from earlier milling eras (1860s to 1910s). These finer sands likely had a greater capacity to drift further into Torch Lake, settling throughout the Lake sediments as a fine material—thus spreading copper and other metal content further throughout Torch Lake. It is unclear how the waste material from scrap metals subjected to leaching was disposed.

4. C&H Regrinding Plant No. 2

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1912
2. Modified (external structure):
3. Ceased operation: 1953
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928.

Building narrative:

The #2 Regrinding Plant was completed in 1912 and in 1913 all of the buildings related to the recrushing plant were completed. 1914 saw the tube mills in the regrinding plant in operation. The plant had a remodel in 1918 and the building continues in operation until the reclamation plant closes in 1953.

The regrinding process was simply old copper tailings being re-milled by more efficient stamps and mills, where a percentage of the missed copper could be collected.

Supporting documents:
See: Benedict, "Milling" (1931); and his *Lake Superior Milling Practice* (1955), Chapter 6, "Fine Grinding."

Building Timeline: C&H Regrinding Plant No. 2:
1912 - Recrushing building complete (123 x 432 ft)
1914 - Tube mills in plant started
1915 - Went into operation in June on small scale, September at full scale
1917 - Sanborn
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1953 - Tailings exhausted, closed

Potential Waste/Pollution Concerns:
C&H Regrinding Plants #1 and #2 were built, along with the shore plant and dredge in Lake Linden, to regrind the reclaimed stamp sands from Torch Lake. In providing a finer-grained sand for the leaching and flotation plants, these facilities contributed to the more widespread of metal-laden sands into Torch Lake after the reclamation process.

5. C&H Regrinding Plant No. 1

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1907-1909.
2. Modified (external structure):
3. Ceased operation: 1953
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928.

Building narrative:

The foundations for the #1 Regrinding Plant were started in 1907 and the entire building was completed in 1909. In 1913 all of the buildings related to the recrushing plant were completed. The plant had a remodel in 1918 and the building continues in operation until the reclamation plant closes in 1953.

The regrinding process was simply old copper tailings being re-milled by more efficient stamps and mills, where a percentage of the missed copper could be collected.

Supporting documents:

Building Timeline: C&H Regrinding Plant No. 1:
1907 - Foundation for regrinding mill #1 started
1908 - Building erected
1909 - Plant complete
1917 - Sanborn
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1953 - Tailings exhausted, closed

Potential Waste/Pollution Concerns:
C&H Regrinding Plants #1 and #2 were built, along with the shore plant and dredge in Lake Linden, to regrind the reclaimed stamp sands from Torch Lake. In providing a finer-grained sand for the leaching and flotation plants, these facilities contributed to the more widespread of metal-laden sands into Torch Lake after the reclamation process.

6. Lake Linden C&H Sub-Station

Significant: Yes
Alternative (common) names for building: Regrinding Plant #2 Sub-Station

Dates:
1. Built: Around 1912 along with Regrinding Plant #2
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928.
From C&H Collection:
MS005-9654, 1931.
MS005-11461, 1948.
MS005-12307, 1960.

Building narrative:

This building was a sub-station located just east of the Regrinding Plant #2. This was where the power was processed and sent to be used in the regrinding mill.

Supporting documents:
The Mining Congress Journal, October 1931, page 546 – East of Regrinding Plant #2, 2 transformers

Building Timeline: Lake Linden Sub-Station:
1917 - Sanborn
1928 - Sanborn
Shown on Drawing '9654' - 1931
Shown on Drawing '11461' - 1948
Shown on Drawing '12307' – 1960

Potential Waste/Pollution Concerns:
After 1930, PCBs were placed in transformers to replace mineral oil. C&H purchased their transformers for all electrical facilities from General Electric and Westinghouse. Both companies regularly utilized PCBs (produced by Monsanto) in all their transformers by the late 1930s. Therefore, when C&H dismantled their electric substations, it is likely that PCB oils were emptied from the transformers (because of the weight of the liquid) before scrapping the metal containers. To date there is no record of PCB disposal in C&H records or among individuals interviewed.

7. Calumet Stamp Mill

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1870s
2. Modified (external structure):
3. Ceased operation: 1944
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928, 1935.
Army Corps of Engineers, Michigan Tech Archives: 1897, 1905, 1924, 1935

Building narrative:

A 50 ft sand wheel was added in 1891 and new boilers were installed and automatic sprinklers were added in 1892. In 1893 the records show that the building included: 11 Leavitt heads with steam cylinders, 14 & 21.5 x 24 inch stroke, Washers, Huntington & Haeberle grinding mills and slime tables, and a Westinghouse driving engine 200HP. In 1904 5 heads were remodeled and in 1905 the entire interior of the mill was remodeled and updated. In 1919 tanks for settling slimes were added to prepare for the reprocessing of tailings. 1944 saw the Calumet mill stop production and it did not start again.

Supporting documents:
See CH Benedict, *Lake Superior Milling Practice,* (1955), Chapters 3-5.

Building Timeline: Calumet Stamp Mill:
1891 - 50 ft sand wheel completed
1892 - Purchased steam fire engine for mills
1892 - Automatic sprinklers installed in milling complex
1893 - Mills and docks lighted by electricity
1896 - Electric Light Plant House at mills completed
1904 - 5 heads remodeled
1905 - Remodel completed
1915 - Fire protection system remodeled
1917 - Sanborn
1919 - Mill now equipped with tanks for settling slimes
1920 - Last of round slime tables replaced by Wiffleys
1920 - Chilean Mills to be replaced by Hardinge Conical Mills
1922 - 9 of 11 units are working
1927 - 2 boilers added, 500 HP capacity
1928 - Sanborn

1935 - Sanborn
1939 - Idle
1943 - Remodel
1944 - Remodel stopped, closed

Potential Waste/Pollution Concerns:
The Calumet Mill began disposing its course-grained stamp sand waste material in Torch Lake in the 1870s. These sands contained copper and other heavy metals. When the Calumet Mill began to process material from the Kearsarge vein, it contained arsenic which was deposited in some of the sands. The Ahmeek, Allouez, and Centennial mines all operated on the Kearsarge vein. It stopped deposition of sands in the 1940s.

8. Hecla Stamp Mill

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1860s (1868?)
2. Modified (external structure): 1892-1893, 1900-1902.
3. Ceased operation: 1921
4. Structure removed: 1924 and 1940.
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928, 1935.
Army Corps of Engineers, Michigan Tech Archives: 1897, 1905, 1924, 1934.
C&H Collection (MTU Archives):
General map of mills, MS002-138-13-millsmap.
MS005-7928, 1917.

Building narrative:

In 1891 they were in the process of erecting a 50 ft sand wheel which was completed in 1892, along with the installation of new boilers for the mill. 1892 also saw automatic sprinklers installed and a new addition to the mill being started which was completed in 1893. A list shows that in 1893 the Hecla Mill had the following equipment: 11 Leavitt heads, equipped similar to Calumet Mill and preparing to place solid anvils under all stamps.

In 1900 the Hecla Mill was preparing for another addition, which was completed in 1902. This addition was powered with electricity and the equipment was contracted through General Electric. In 1919 the mill was equipped with tanks for settling slimes in preparation for the reprocessing of tailings.

The Hecla Mill closed in 1921 and was dismantled in 1924, with remaining equipment and structures dismantled in 1940.

Supporting documents:
See CH Benedict, *Lake Superior Milling Practice,* (1955), Chapters 3-5.

Building Timeline: Hecla Stamp Mill:
1917 – Sanborn
1921 – Ceased operation
1924 - Hecla Flotation Plant Dismantled
1928 - Sanborn

1935 - Sanborn
1940 - Sand wheels scrapped

Potential Waste/Pollution Concerns:
The Hecla Mill began disposing its course-grained stamp sand waste material in Torch Lake in the 1860s. These sands contained copper and other heavy metals. When the Hecla Mill began to process material from the Kearsarge vein, it contained arsenic which was deposited in some of the sands. The Ahmeek, Allouez, and Centennial mines all operated on the Kearsarge vein. It stopped deposition of sands in 1921.

9. Still House

Significant: Yes
Alternative (common) names for building:

Dates:
1. Built: Approximately at time of Leaching Plant (1914-1915)
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
C&H Collection (MTU Archives):
General map of mills, MS002-138-13-millsmap.
MS005-7928, 1917.
MS005-9654, 1931.

Building narrative:
To date little information has been found on the Still House, which is associated with the Leaching Plant, aiding in the distillation process associated with ammonia leaching of copper.

Supporting documents:
The Mining Congress Journal, October 1931, page 546 – 1 turbo generator

Building Timeline: Still House:
Shown on 'General Map of Mills'
Shown on Drawing '7928' - 1917
1 Turbo Generator according to Drawing '9654' – 1931

Potential Waste/Pollution Concerns:
Not enough information to assess.

10. C&H Power Plant

Significant: Yes
Alternative (common) names for building:

Dates:

1. Built: 1902
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed: 2013
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928, 1935.
Army Corps of Engineers, Michigan Tech Archives: 1962, 1970.
C&H Collection (MTU Archives):
General map of mills, MS002-138-13-millsmap.
MS005-7928, 1917.
MS005-9654, 1931.
MS005-9966, 1934.
MS005-11461, 1948.
MS005-12307, 1960.

Building narrative:

In 1902 a new steel electric power house was erected and it went into commission in 1903. 1905 saw the addition of 2 large engines, which shows it having 9,000 HP engines in 1906. The Power Plant could generate 2,000 KW in 1907. In 1917 the building was fireproofed and in 1929 the obsolete electrical equipment was scrapped. A new 2000 KW low pressure unit was installed which was operational by 1920.

In 1947 C&H planned new generating facilities, including two new 1000 HP diesel-electric locomotives and a diesel-electric locomotive crane, which was completed in 1949. The power plant closed with the company in 1968 and the building was raised in 2013.

Supporting documents:
McIntosh and Burgan, "Electric Power Generation," *The Mining Congress Journal*, October 1931. (see p. 546:- 3 turbo generators with transformers, 1 circulating pump with transformer, and 2 synchronous condensers).

Building Timeline: C&H Power Plant:
1902 - New steel electric power house has been erected
1902 - Tunnel for the electric cables to connect the Power House to the mills has been completed

1903 - Power House is in commission
1905 - 2 large electric additions to Electric Power Plant in process
1906 - Addition to Electric Power Plant complete, 9,000 HP engines, 2 independent cable lines connect the Power Plant with the mine
1907 - Engine and generator of 2,000 KW at Electric Power Plant at mills
1909 - Erected power line to Lake Superior Water Works to pump water from the lake to the mills
1917 - Electric Power House fireproofed
1917 - Sanborn (Power House)
1928 - Sanborn (Power Plant)
1929 - Obsolete electrical equipment has been scrapped and a 2000 KW low pressure unit is being installed
1930 - 2000 KW low pressure unit operational, 2 turbines
1935 - Sanborn (Power Plant)
1947 - installation of new generating facilities is planned, should be done in early 1949
1948 - addition is nearing completion
1949 - New power plant is in full operation and gives evidence of meeting every expectation
Shown on 'General Map of Mills'
Shown on Drawing '7928' - 1917
Shown on Drawing '9654' - 1931
Shown on Drawing '9966' - 1934
Shown on Drawing '11461' - 1948
Shown on Drawing '12307' – 1960

Potential Waste/Pollution Concerns:
After 1930, PCBs were placed in transformers to replace mineral oil. C&H purchased their transformers for all electrical facilities from General Electric and Westinghouse. Both companies regularly utilized PCBs (produced by Monsanto) in all their transformers by the late 1930s. Therefore, when C&H dismantled their electric substations, it is likely that PCB oils were emptied from the transformers (because of the weight of the liquid) before scrapping the metal containers. To date there is no record of PCB disposal in C&H records or among individuals interviewed.

The C&H Power Plant was an extensive operation, powering C&H facilities as far south as Tamarack Reclamation Plant, as far west as the C&H and Tamarack Water Works, and from Calumet north to Phoenix and Cliff mines. In 1943, C&H extended its power lines to Quincy Reclamation Plant to service the dredge, shore plant, and reclamation works. The coal supplied for power was delivered at the C&H coal dock in Hubbell, pulverized at the Coal Pulverization Plant (after 1917), and utilized as the most efficient means to deliver power. A major by product of coal use (and pulverization) is fly ash that is dispersed through the local environment through smokestacks and accumulates in furnaces. Interviewee #1 indicated that the remaining furnace fly ash was probably deposited into Torch Lake from the smelter yard. PAHs (polyaromatic hydrocarbons) are one hazardous waste produced by coal burning and fly ash production.

11. C&H Boiler House

Significant: Yes
Alternative (common) names for building:

Dates:
1. Built: 1907
2. Modified (external structure): 1929
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1917, 1928, 1935.
C&H Collection (MTU Archives)
General map of mills, MS002-138-13-millsmap.
MS005-7928, 1917.

Building narrative:

The boiler house was built in 1896 to help power the C&H stamp mills located in Lake Linden. The boilers at the Water Works were moved to this new facility in 1897 and 4 more boilers were added in 1900. This facility quickly became obsolete and a new one was built in 1907 and completed in 1908 where it remained, situated next to the Power House. In 1920 the boiler house had massive renovations. A concrete foundation was added and the side walls were coated with concrete to prevent fire. In 1929 an addition of steel and glass was added to the main furnace building. This building closed with the company in 1968.

Supporting documents:

Building Timeline: C&H Boiler-House:
1893 - Addition planned, 11 boilers at present
1895 - Foundations laid for addition to mill boiler house and stack
1896 - Boiler House erected near mills
1897 - Boilers at the Water Works boiler house moved to new Boiler House near mills
1899 - Boilers overhauled
1900 - 4 boilers added
1907 - Foundation for new Boiler House at mills started
1908 - Completed
1910 - Part of old mill boiler house has been torn down
1917 - Sanborn
1920 - Boiler House reconstruction, Concrete foundation and side walls coated with concrete
1922 - Remodeled

1928 - Sanborn
1930 - New turbines of 8,750 KW capacity
1935 – Sanborn

Potential Waste/Pollution Concerns:
Waste concerns would likely be associated with the burning of coal in furnaces and coal ash byproducts.

12. C&H Coal Dock Sub-Station

Significant: Yes
Alternative (common) names for building:

Dates:

1. Built: ?
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed: ?
5. Last time seen on map/aerial photo:

Maps available:
C&H Collection (MTU Archives):

General map of mills, MS002-138-13-millsmap.
MS005-6967, 1917 – blueprints.
MS005-7928, 1917.
MS005-9654, 1931.
MS005-11461, 1948.
MS005-12307, 1960.

Building narrative:

This building was the sub-station at the coal dock which allowed the power to be transmitted to the machinery and buildings in the area. The foundations for this building are still present on the landscape and the raised platforms where the transformers sat are also visible.

Supporting documents:
The Mining Congress Journal, October 1931, page 546 – 2 transformers

Building Timeline: Coal Dock Sub-Station:
Shown on 'General Map of Mills'
Shown on Drawing '7928' - 1917
Blueprint on Drawing '6967' - 1917
Blueprint on Drawing '7928' - 1917
2 transformers according to Drawing '9654' - 1931
Shown on Drawing '11461' – 1948
Shown on Drawing '12307' – 1960

Potential Waste/Pollution Concerns:
After 1930, PCBs were placed in transformers to replace mineral oil. C&H purchased their transformers for all electrical facilities from General Electric and Westinghouse. Both companies regularly utilized PCBs (produced by Monsanto) in all their transformers by the late 1930s. Therefore, when C&H dismantled their electric substations, it is likely that PCB oils were emptied from the transformers (because of the weight of the liquid) before scrapping the metal containers. To date there is no record of PCB disposal in C&H records or among individuals interviewed.

13. C&H Mineral House

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1927-1929
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed: Still exists
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928, 1935.
C&H Collection (MTU Archives):
General map of mills, MS002-138-13-millsmap.
MS002-138-17-9003, 1929.
MS005-7928, 1917.

Building narrative:

The mineral house began construction in 1927 and was completed in 1929. It had a reinforced concrete foundation and compartment walls for mineral storage for the smelter, including 10 main compartments for 15,000 tons of material and a 7.5 ton overhead electric crane carrying a clam shell bucket for handling the mineral. The mineral house closed in 1968 with the company and is still standing.

Supporting documents:

Building Timeline: C&H Mineral House:
1927 - Process of being built
1928 - Sanborn
1929 - Operational
1935 - Sanborn

Potential Waste/Pollution Concerns:
Material stored from the leaching and flotation plants in preparation for the smelter. No known information on waste and contamination concerns.

14. C&H Oil House

Significant: Yes
Alternative (common) names for building:

Dates:
1. Built:
2. Modified (external structure):
3. Ceased operation:
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928, 1935.

Building narrative:
Other than its appearance on Sanborn maps, there is no information found to date on the Oil House.

Supporting documents:

Building Timeline:

15. C&H Coal Pulverization Plant

Significant: Yes, not for PCBs
Alternative (common) names for building:

Dates:
1. Built: 1924
2. Modified (external structure):
3. Ceased operation: probably 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
C&H Collection (MTU Archives):
MS002-138-17-9003, 1929.
MS002-138-13-millsmap-001, date unknown.

Building narrative:

This building pulverized the coal delivered to the C&H coal dock for use in the smelter and the Power House in Lake Linden. There is expected to be pollution in the area related to coal waste.

Supporting documents:

See: HR Collins, "The Use of Pulverized Coal" *Engineering & Mining Journal,* 1918. Also, FH Haller, "Transportation System and Coal Dock" *Mining Congress Journal,* 1931.

From C&H Collection (MTU Archives): There is little information to date on the building of this plant. However, much discussion of coal use and the benefits of pulverization for efficient electrification runs through the C&H Collection. A sample below describes the process and the facility, helping to assess it importance and potential for creating hazardous waste:

> C&H Smelting Works No. 20 Furnace Building, No. 20, 21 Coal Storage & Burning System Blueprint – 1927; Drawing # 9030. Box 125, Folder 15.
>
> Drawing of the proposed coal crushing plant from Stevens-Adamson Mfg. Co. for C&H
> Smelting Works. Box 126, Folder 13.
>
> Box 126, Folder 14.

“The process of crushing, drying and pulverizing fuel should be accomplished in a separate building used for no other purposes. This building should preferably be detached, but where this is not practicable it should be separated by a blank masonry or concrete wall containing no openings other than those necessary for the passing of pipes and shafting. The building should be constructed of incombustible materials and specially designed to secure minimum lodgement of dust and to relieve the force of an explosion through its roof and walls without danger to its frame. The frame should preferably be of steel with light non-bearing walls (except fire walls) constructed of materials such as stucco on metal lath, tile, metal or other similar incombustible material and with roof of monitor or gable type and all secured in such a manner as to give way readily under pressure of explosion. The monitors with louvered or glass sides or sky-lights should have a horizontal area not less than one-tenth of the horizontal area of the roof.

In order that the venting of explosion may be more readily facilitated, a portion of the exterior walls equal to not less than 10% of the combined area of the enclosing walls should be of glass. All glazing should be by means of thin glass not exceeding 1/8” in thickness.

Coal pulverizing mills and coal dryers should be equipped with suction fans or other approved means for removing dust. The collection of dust to take place as near the point of origin as possible and suction fans to discharge outside of building or into metal cyclone collectors. Dust collecting devices should be constructed of incombustible material and contain no cloth partitions, tubes or bags. All elevators including boots, legs and heads, or screw conveyors should be constructed of incombustible materials. Conveyors for supplying coal pulverizing mills should be provided with approved magnetic separators between source of supply and mill feed bins. Elevator heads, cyclone collectors or storage bins for handling or storing pulverized coal should be provided with approved vents exhausting outside of building. Machinery and other parts comprising the crushing, drying, pulverizing and conveying system should be effectively electrically grounded. All stationary lights should be protected with dust proof globes and wire guards. Smoking and the use of open lights or torches should be prohibited. All motors, switches and other electrical devises should conform to the standards of the National Electrical Code.”

-Copied from Michigan Inspection Bureau’s letter dated July 20, 1923.

Box 126, Folder 14.

“All of the above goes to show that pulverized coal if delivering the goods and that higher efficiencies can be obtained with it than by any other method, and that pulverized coal enables them to operate their plants more economically.”

-Fuller Engineering Co. letter to C&H, February 3, 1923

Box 126, Folder 20.

There were narrow gauge railroad tracks running between the Coal Pulverizing Plant and the No. 22 Stack.

Box 127, Folder 1.
September 18, 1953, flow-sheet showing the present flow in our Coal Pulverizer Plant.
The plant used roller mills to break up the coal.

Building Timeline:

1924 - Plant construction is underway
1924 - Plant Sketches
1927 - C&H Smelting Works No. 20 Furnace Building, No. 20, 21 Coal Storage & Burning System Blueprint; Drawing # 9030
1928 - Sanborn
1935 - Sanborn
1941 - Brick Dust Mill Air Separating System Blueprints (6' Mechanical separator – single whiz. Chromium Min. & Smelt. Corp. Ltd., Raymond Pulverizer Division)
1943 - Narrow gauge railroad tracks running between the Coal Pulverizing Plant and the No. 22 Stack
1946 - Raymond Pulverizer Division proposal
1953 - Flow-sheet showing the present flow in the Coal Pulverizer Plant
1960 - Roller mills were in use at the Pulverizing Plant
1968 - C&H sold to Universal Oil Products
1969 - All of Calumet Division closed on April 8, 1969 with $13 mil writedown of assets

Potential Waste/Pollution Concerns:

The coal supplied for power was delivered at the C&H coal dock in Hubbell, pulverized at the Coal Pulverization Plant (after 1917), and utilized as the most efficient means to deliver power. A major by product of coal use (and pulverization) is fly ash that is dispersed through the local environment through smokestacks and accumulates in furnaces. Interviewee #1 indicated that the remaining furnace fly ash was probably deposited into Torch Lake from the smelter yard. PAHs (polyaromatic hydrocarbons) are one hazardous waste produced by coal burning and fly ash production.

16. C&H Smelting & Refining Plant

Significant: Yes
Alternative (common) names for building:

Dates:

1. Built: 1887
2. Modified (external structure): 1930
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928, 1935.
Army Corps of Engineers, Michigan Tech Archives: 1897, 1905, 1924, 1934, 1943, 1950, 1962, 1970.
C&H Collection (MTU Archives):
General map of mills, MS002-138-13-millsmap.
MS002-138-17-9003, 1929.
MS005-9654, 1931.
MS005-12307, 1960.

Building narrative:

The Smelting and Refining Plant was constructed in 1887 and in 1893 it covered about 30 acres, was connected to the mills by short railway, 4 stone furnace buildings – 80 x 130 ft, and had a water source from an artesian well. In 1924 the smelter was the central plant that pulverized the coal used as fuel, about 12 tons of coal per hour. In 1930 the smelter main furnace building was extended 45 ft north. In 1944 the smelter had a process for removing arsenic from soda slag by leaching the later with soda solution. Two major furnaces were rebuilt in 1957 and another two in 1965, but the smelter closed in 1968 with the company.

Supporting documents:
See: Lovell and Kenny, "Present Smelting Practice" *Mining Congress Journal.* 1931.

<u>From C&H Collection (MTU Archives):</u> These selections illustrate the issues of waste associated with the smelting facilities (slag, fly ash)

Box 127, Folder 30.
Aug. 21, 1925, one slag car requires five to six hours to solidify before it can be dumped, which means that C&H needs more slag cars. They must dispose of at least 130 tons of waste slag per day, and each car averages 6.5 tons of slag.

Box 199, Folder 20.

May 6, 1954, memorandum saying that fly ash was blended into the fertilizer. Fly ash is held in inventory at the Smelter and that it is put through a gravity concentrator to concentrate the copper out of it to about 70%. Overall, it is much more efficient to use the fly ash in the fertilizer than to purify it and extract the copper.

Box 201, Folder 25.

Chemical removal of soot and slag from boiler furnaces & documents discussing flue dust and how to recycle or reduce it.

Box 86, Folder 20.

Smelter has decreased activities, so C&H has told them to buy more scrap metal to process – 1961.

Box 86, Folder 22.

Procedure at the smelter (1969) & large smelter flow sheet (1946).

From *C&H News and Views, August 1946: Processing "Copper Mud"*

After a period of experimentation, C&H introduces a new material to its secondary copper department (reclaiming copper from waste materials), with the treatment of "Copper Mud."

From research notes: The latest addition to this family of processes is one which makes possible the treatment of "Copper Mud", a waste product resulting from the drawing of copper wire. The material as received is a pasty mixture of fine copper, oil, grease, floor sweepings, etc., having an average copper content of the order of 25%, and a combination of animal, vegetable and mineral oils of approximately 40%. As received, the material is not suitable for direct furnacing due to the presence of the high percentage of fat and water; but after several months of experimentation, a procedure was worked out which not only makes possible the recovery of the copper in a highly concentrated useful form, but fat by-products as well. The equipment required to process the material involves a large lead-lined digester, filters, grease accumulation tanks, copper recovery tank, and a 10,000-gallon storage tank for grease.

Installation of the various units was started during June and production on a limited basis began the middle of August. It is expected that the unit will be operating on a continuous basis by September first.

The copper recovered as a metallic concentrate contains approximately 75% copper and in this form is suitable for direct furnacing with other concentrates. The fat is reclaimed as a semi-clear liquid and will be accumulated in 8,000 to 10,000-gallon batches (40,000 to 60,000 lbs.) for shipment in tank cars.

The fat or grease is classified as an inedible oil, and will be shipped into the Chicago district for processing into oleic and stearic acids and for the manufacture of industrial soaps.

It is anticipated that the process will add several hundred thousand pounds of copper per month to the smelter intake, with the recovery of from 20,000 to 30,000 gallons by-product fat which can be readily marketed at an attractive price." (p. 1)

Building Timeline: C&H Smelting & Refining:
1887 - Under construction
1893 - Covers about 30 acres, connected to mills by short rail, 4 stone furnace buildings (80 x 130 ft), water source from artesian well
1902 - 5 furnaces rebuilt
1913 - Smelting at Buffalo, NY discontinued, all smelting done on Torch Lake
1924 - Central Plant for furnishing pulverized fuel added
1926 - Second Refining Furnace under construction (Electrically operated, 40 ft Clark casting machine, 800 KW turbo generator being installed)
1927 - Refining Furnace in operation, melting furnace being installed
1928 - Sanborn
1928 - Melting Furnace in operation, 800 HP waste heat boiler installed
1929 - Small, hand-dipped furnaces being dismantled, furnaces supply steam to a turbo-generator that furnishes electric current for power and lighting
1935 - Sanborn
1944 - Process for removing arsenic from soda slag by leaching the later with soda solution is now in regular operation, new refining furnace installed
1946 - 2 furnaces rebuilt
1947 - new refining furnace
1956 - 2 major furnaces rebuilt
1965 - 2 furnaces rebuilt
1968 - C&H sold to Universal Oil Products
1969 - All of Calumet Division closed on April 8, 1969 with $13 mil writedown of assets

Potential Waste/Pollution Concerns:
The major waste by-products from the smelter were slag and fly ash. C&H typically loaded slag (probably granulated slag) onto special rail cars whose sides dropped open for dumping of the slag. It is likely that the slag deposits adjacent to the smelter on the south (and north of Hubbell Beach) was the primary deposit site for smelter slags. Granulated slags (as opposed to hardened lump or rock-like slag) are more vulnerable to sloughing of heavy metals that remain in the smelter waste. Fly ash deposited in the furnaces was likely disposed of in Torch Lake. However, in the 1950s, C&H conducted studies of the copper content of fly ash to determine if it would be cost-effective to process the ash and retrieve the copper. It is unclear whether C&H ever developed a copper recovery program from fly ash.

The smelter yard is another location of possible hazardous waste contamination. In 1945, C&H launched its "Secondary Metal Department"—an indication that reclamation of copper from scrap metal waste had become an important part of the business. *C&H News and Views* has photographs of burning some of the secondary waste material before treating it in the smelter: co-axial telephone cable, stripping insulation from armored Navy cable, burning insulation and grease from motor parts, etc. (July, 1945 issue). In addition, interviewees mention that the smelter yard was a site for burning copper wire to remove the insulation before smelting.

Dismantling of the Smelter furnaces would have left brick that had been contaminated with heavy metals. It is likely this material was deposited in dump locations or possibly in Torch Lake, or along the slag piles south of the Smelter.

17. C&H Smelter Electric Shop

Significant: Yes
Alternative (common) names for building:

Dates:
1. Built: 1887
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928, 1935.
C&H Collection (MTU Archives):
MS002-138-17-9003, 1929.

Building narrative:
To date there is no available information on the Electric Shop at the Smelter, other than its appearance on Sanborn maps.

Supporting documents:

Building Timeline: C&H Electric Shop (in the Smelter):
1928 - Sanborn
1935 - Sanborn

18. C&H Smelter Power Plant

Significant: Yes
Alternative (common) names for building:

Dates:

1. Built: 1887
2. Modified (external structure):
3. Ceased operation: 1968
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1935.
C&H Collection (MTU Archives):
MS002-138-17-9003, 1929.

Building narrative:

This building was actually a portion of the larger smelter building, which housed the electrical transformers and turbo generators to power the smelter facilities.

Supporting documents:
The Mining Congress Journal, October 1931, page 546 – 1 turbo generator

Building Timeline: C&H Smelter Power Plant:
1935 Update of 1928 - Sanborn
Blueprint on Drawing '9003' - 1929
1 Turbo Generator according to Drawing '9654' - 1931
Shown on Drawing '11461' - 1948
Shown on Drawing '12307' – 1960

Potential Waste/Pollution Concerns:
PCBs, as noted in description of Coal Dock Substation and C&H power plant.

19. C&H Electrolytic Plant

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1912
2. Modified (external structure):
3. Ceased operation: 1922
4. Structure removed: Still exists – currently known as Osmose (PCI)
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928.
General map of mills, MS002-138-13-millsmap.
C&H Collection (MTU Archives)
    MS002-138-17-9003, 1929.

Building narrative:

The Electrolytic Plant foundation was completed in 1912 and was 155 x 270 ft. The facility closed in 1922 and did not re-open.

The Electrolytic Plant purified copper through dissolving the unprocessed copper on electrodes and electroplating it. This only lasted a few years in the Keweenaw as the process did not work well on native copper.

Supporting documents:
See entries in H. Steven's *Mine Handbook* for C&H between 1912 and 1922 for a short history of the electrolytic plant which proved to be unprofitable for Lake Superior copper (i.e. it did not have an adequate silver content to the ore, making the process successful).

Building Timeline: C&H Electrolytic Plant:
1922 - Not operated since 1922
1928 - Sanborn

Potential Waste/Pollution Concerns:
No information available.

20. C&H Acid Treating Plant

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1919?
2. Modified (external structure):
3. Ceased operation: 1922?
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Sanborn Fire Insurance Maps, Michigan Tech Archives: 1928.

Building narrative:

This building is believed to have been associated with the Electrolytic Plant and operations would have ceased in 1922.

Supporting documents:

Building Timeline: C&H Acid Treating Plant:
1928 - Sanborn

21. Jos. Ethier & Co. Lumber

Significant: No
Alternative (common) names for building:

Dates:
1. Built: 1898
2. Modified (external structure):
3. Ceased operation:
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Army Corps of Engineers, Michigan Tech Archives: 1905, 1924, 1934.

Building narrative:

Jos. Ethier & Co. was a lumber company in Hubbell, MI. In 1905 Joseph H. LeBlanc bought out Ethier's share and the business was renamed after LeBlanc and sons.

Supporting documents:
None, other than appearance on maps.

Building Timeline:
Not known.

22. Hubbell Garbage Dump

Significant: Yes
Alternative (common) names for building: Hubbell Beach, Hubbell Dump

Dates:
1. Built: Unknown
2. Modified (external structure):
3. Ceased operation: pre-1984
4. Structure removed:
5. Last time seen on map/aerial photo:

Maps available:
Army Corps of Engineers, Michigan Tech Archives: 1988 – Ramp at Hubbell Beach

Site narrative:

The Hubbell Dump is believed to be the municipal dump for the Hubbell area as well as Torch Lake Township. It was located just south of the C&H Smelter, which has led researchers to believe that it was also used as a dump for smelter slag and other company waste. It was cleaned up in the 1980s and turned into a park with a beach and boat launch for the local community. Archival and Township records have yet to provide any substantial information about the area.

Supporting documents:

Torch Lake Township Recreational Plan 2009-1013. Prepared by WUPPDR (no date).
MTU Archive - Vertical Files: Townships – Torch Lake.

> Hubbell dump closed before 1984; area was using the Calumet Twp. landfill by then.
> Interview #3

See Summary for Interview #3: description of types of materials deposited in dump site.

Timeline:
To date, no known dates on first and last use of this dump site.

2.2 – Torch Lake Building Chronologies

Torch Lake Building Chronologies
Phase 1: Lake Linden & Hubbell

Google Maps with Building Outlines

Houghton County Electric Light & Power (Sub-Station #9) – Lake Linden

Houghton County Electric Light & Power (Sub-Station #9):
1917, 1928, 1935 - Sanborns

C&H Mills & Reclamation – Lake Linden

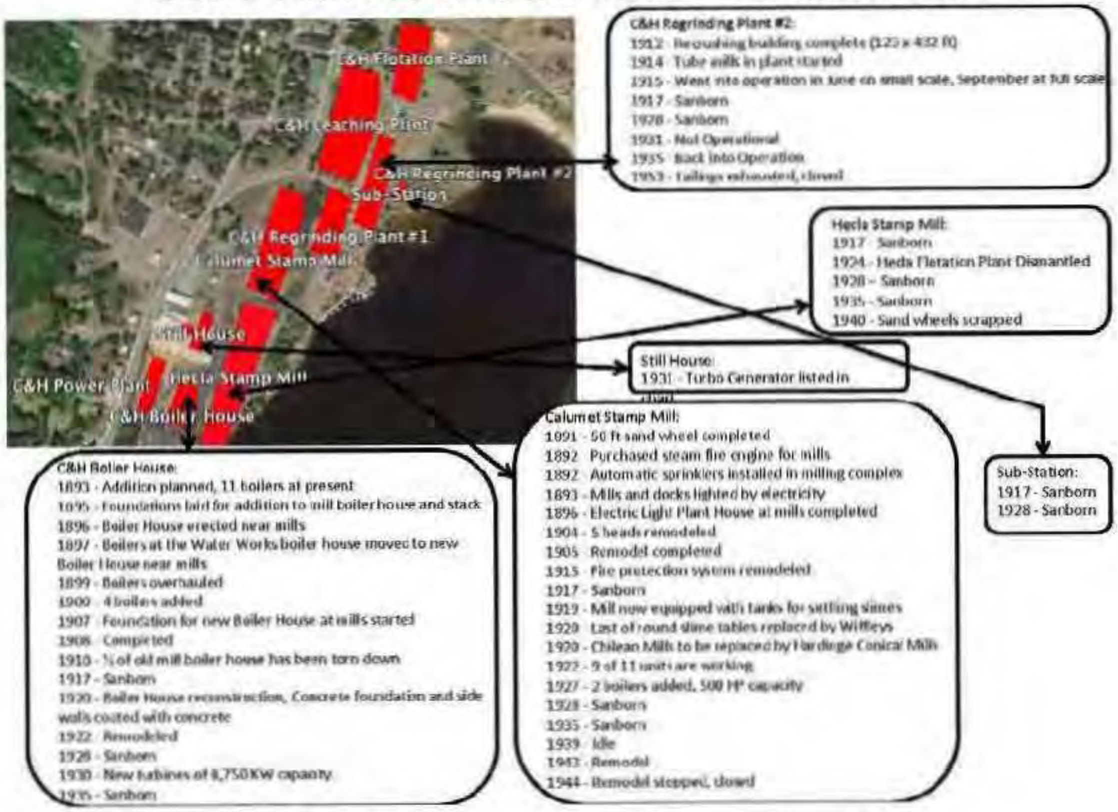
C&H Flotation Plant:
1915 - Oil flotation experiments underway
1917 - Flotation experiments successful
1918 - Flotation plant to treat slimes from Regrinding Plant should be in commission in summer
1919 - 2/3 of slimes from Regrinding Plant are treated by flotation, building need extending
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1955 - Tailings exhausted, closed

C&H Leaching Plant:
1934 - Ground broke for new Leaching Plant
1915 - Building complete, ammonia
1916 - Processing began in July
1917 - Sanborn
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1942 - Leaching process in use on scrap from copper and brass coated steel
1955 - Rest of Reclamation Plant closed, Leaching still in operation

C&H Power Plant:
1902 - New steel electric power house has been erected
1902 - Tunnel for the electric cables to connect the Power House to the mills has been completed
1903 - Power House is in commission
1905 - 2 large electric additions to Electric Power Plant in process
1906 - Addition to Electric Power Plant complete, 9,000 HP engines, 2 independent cable lines connect the Power Plant with the mine
1907 - Engine and generator of 2,000 KW at Electric Power Plant at mills
1909 - Erected power line to Lake Superior Water Works to pump water from the lake to the mills
1917 - Electric Power House fireproofed
1917 - Sanborn (Power House)
1918 - Sanborn (Power Plant)
1939 - Obsolete electrical equipment has been scrapped and a 2200 KW low pressure unit is being installed
1940 - 2000 KW low pressure unit operational, 2 turbines
1935 - Sanborn (Power Plant)
1947 - Installation of new generating facilities is planned, should be done in early 1949
1948 - addition is nearing completion
1949 - New power plant is in full operation and gives evidence of meeting every expectation

C&H Regrinding Plant #1:
1907 - Foundation for regrinding mill #1 started
1908 - Building erected
1908 - Plant complete
1917 - Sanborn
1928 - Sanborn
1931 - Not Operational
1935 - Back into Operation
1953 - Tailings exhausted, closed

C&H Mills & Reclamation – Lake Linden



Coal Dock – Hubbell

Smelter Complex – Hubbell

Mineral House:
1927 - Process of being built
1928 – Sanborn
1935 - Operational
1935 – Sanborn

C&H Smelter:
1887 - Under construction
1898 - Covers about 30 acres, connected to mills by short rail, 4 stone furnace buildings (103 x 110 ft), water source from artesian well
1902 - 5 furnaces rebuilt
1919 - Smelting at Buffalo, NY discontinued, all smelting done on Torch Lake
1924 - Central Plant for furnishing pulverized fuel added
1926 - Second Refining Furnace under construction (Electrically operated, 40 ft Clark casting machine, 800 KW turbo generator being installed)
1927 - Refining Furnace in operation, melting furnace being installed
1928 - Sanborn
1928 - Melting Furnace in operation, 800 HP waste heat boiler installed
1929 - Small, hand-dipped furnaces being dismantled, furnaces supply steam to a turbo-generator that furnishes electric current for power and lighting
1935 - Sanborn
1944 - Process for removing arsenic from soda slag by leaching the later with soda solution is now in regular operation, new refining furnace installed
1946 - 2 furnaces rebuilt
1947 - new refining furnace
1956 - 2 major furnaces rebuilt
1965 - 2 furnaces rebuilt
1968 - C&H sold to Universal Oil Products
1969 - All of Calumet Division closed on April 5, 1969 with $13 mil writedown of assets

Smelter Complex – Hubbell

Coal Pulverization Plant:
1924 - Plant construction is underway
1924 - Plant Sketches
1927 - C&H Smelting Works No. 20 Furnace Building, No. 20, 21 Coal Storage & Burning System Blueprint; Drawing # 9030
1928 - Sanborn
1935 - Sanborn
1941 - Brid. Dust Mill Air Separating System Blueprints (6' Mechanical separator - single whiz, Chromium Min. & Smelt. Corp. Ltd., Raymond Pulverizer Division)
1943 - Narrow gauge rail tracks running between the Coal Pulverizing Plant and the No. 22 Stack
1946 - Raymond Pulverizer Division proposal
1953 - Flow-sheet showing the present flow in the Coal Pulverizer Plant
1960 - Roller mills in use at the Pulverizing Plant

Electric Shop:
1928 - Sanborn
1935 - Sanborn

C&H Smelting Power Plant:
1935 Update of 1928 - Sanborn

Acid Treating Plant:
1928 - Sanborn

Electrolytic Plant:
1922 - Not operated since 1922

Section 3: GEOSPATIAL DATA AND MAPS

Phase 1: North End of Torch Lake to Hubbell Beach

3.1 – Geospatial Data Products

This section describes all the newly available geospatial data and the associated maps, which are serve as a graphical representation of the data provided. MTRI has made available Sanborn and other generic blueprints, which cover the 18 buildings listed in Appendix A of the current Phase 1 statement of work. Here are the 18 buildings which MTRI has provided GIS-ready data, and associated maps:

- Houghton County Electric Light & Power (Sub-Station #9)
- C&H Flotation Plant
- C&H Leaching Plant
- C&H Regrinding Plant No. 2
- C&H Regrinding Plant #1
- C&H Regrinding Plant #2
- Lake Linden Substation
- Calumet Stamp Mill
- Hecla Stamp Mill
- Still House
- C&H Power Plant
- C&H Boiler House
- Coal Dock Sub-Station
- C&H Mineral House
- C&H Smelting and Refining
- C&H Electric Shop (in smelter)
- C&H Smelter Power Plant
- C&H Electrolytic Plant
- C&H Acid Treating Plant

These data have been previously shared with MDEQ and Weston Solutions Inc. A Compact Disc with these data and reports will be delivered to the MDEQ, however these data and maps can also be found at the following address:

ftp://ftp.mtri.org/pub/Torch_Lake_GIS/Revised_Maps_and_BluePrints/

The following will breakdown the GIS-ready GeoTiff file name; the buildings which are located within each file and map figure numbers which are below.

1. File Name: 1928LakeLindenAug1928Sheet7b_CoElec.tif;
   Building(s) Located: Houghton Count Electric Light and Power
   Figures 1 and 2

2. File Name: 1928LakeLindenAug1928Sheet8.tif
   Building(s) Located: C&H Flotation Plant, Sub-Station, C&H Leaching Plant, C&H Regrinding Plant No. 1, C&H Regrinding Plant No. 2, Calumet Stamp Mill, Hecla Stamp Mill, Still House, C&H Boiler House, C&H Power Plant
   Figures 3 and 4

3. File Name: 1928LakeLindenAug1928Sheet1index_HubbellTamarackNorth.tif
   Building(s) Located: Mineral House, Electric Shop, C&H Smelter, C&H Smelter Power Plant, Electrolytic Plant, and Acid Treating Plant.
   Figures 5 and 6

4. File Name: MS002-138-13-millsmap-001_georef.tif
   Building(s) Located: Coal Dock Sub-Station
   Figures 7 and 8

5. File Name: MS002-138-17-9003-georef.tif
   Building(s) Located: C&H Smelting, Electric Shop, and Mineral House
   Figures 9 and 10

6. File Name: MS005-6967-georef.tif
   Building(s) Located: Coal Dock Sub-Station
   Figures 11 and 12

7. File Name: MS005-7928-georef.tif
   Buildings(s) Located: Hecla Stamp Mill, Still House, C&H Power Plant, C&H Boiler-House, Coal Dock Sub-Station, Mineral House
   Figures 12 and 13

Figure 1: Here, the Sanborn GeoTiff file "1928LakeLindenAug1928Sheet7b_CoElec.tif" can be seen with the outline of the Houghton County Electric Light & Power Building overlaid upon the data.

Figure 2: Similar to Figure 1, this map shows the location of the Houghton County Electric Light & Power Building. However, the underlying Sanborn data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

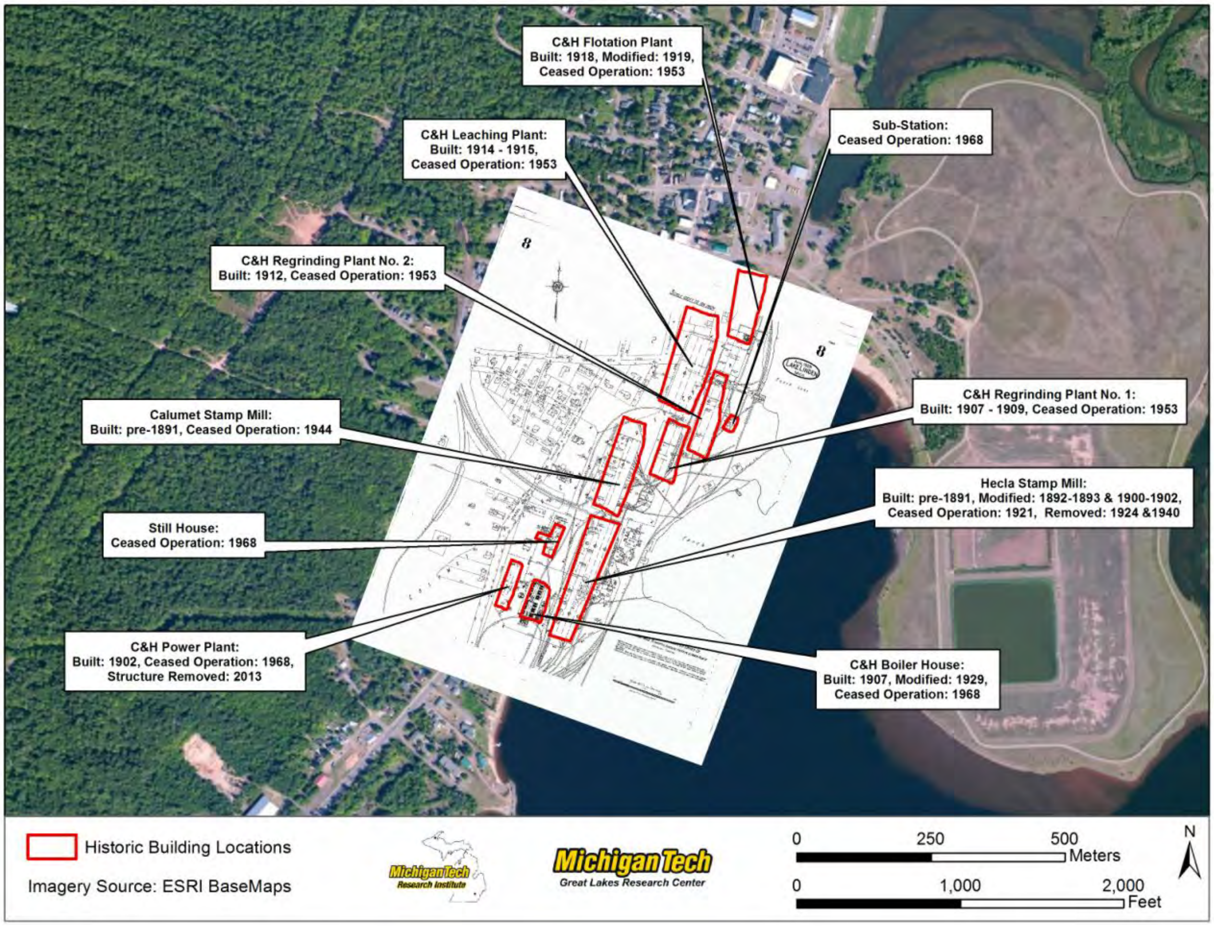


Figure 3: Here, the Sanborn GeoTiff file " 1928LakeLindenAug1928Sheet8.tif" can be seen with the outlines of multiple buildings, which include: C&H Flotation Plant, Sub-Station, C&H Regrinding Plant No. 1, C&H Regrinding Plant No. 2, C&H Leaching Plant, Hecla Stamp Mill, Calumet Stamp Mill, Still House, C&H Boiler House and the C&H Power Plant

Figure 4: Similar to Figure ,3 this map shows the various buildings listed in Figure 3. However, the underlying Sanborn data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

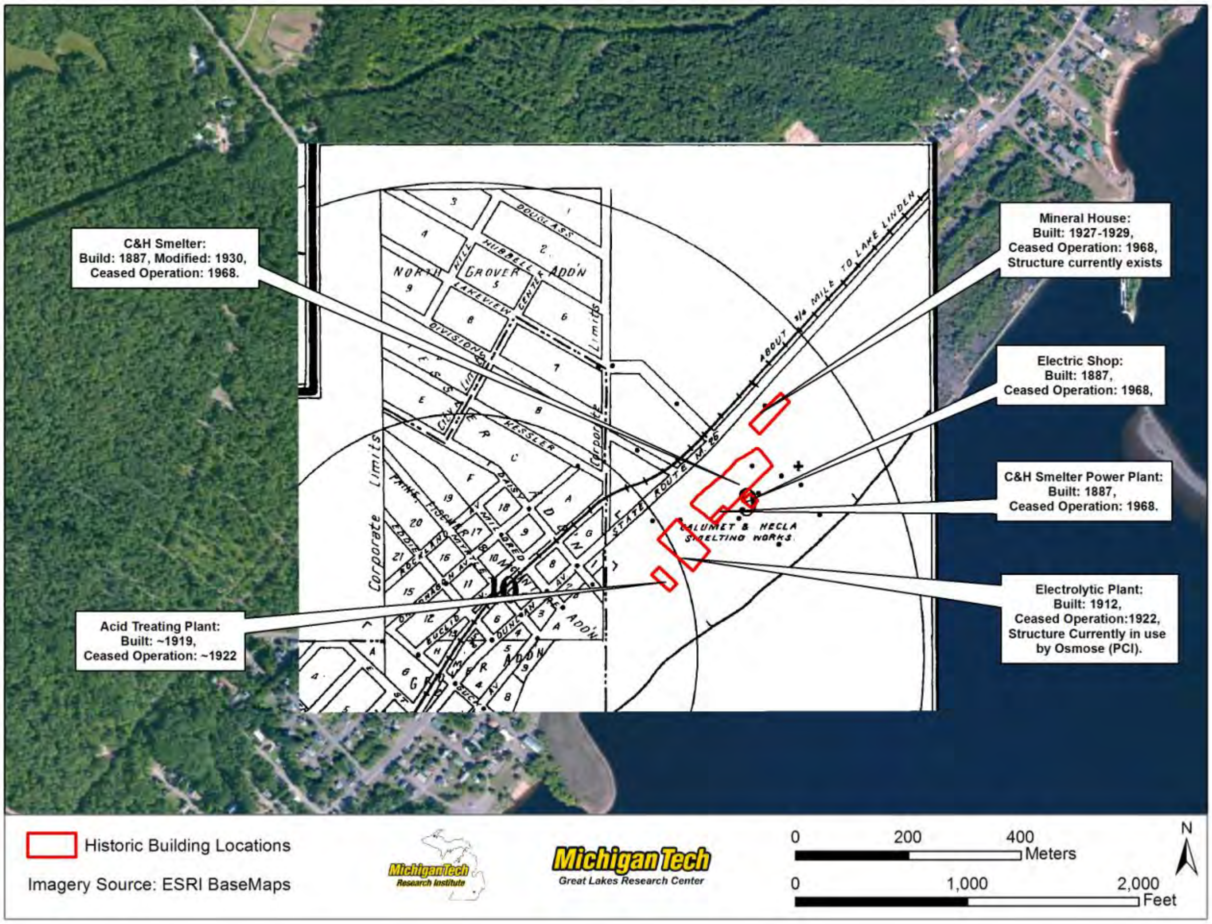


Figure 5: The Sanborn GeoTiff file "1928LakeLindenAug1928Sheet1_index_HubbellTamarckNorth.tif" can be seen with the outlines of multiple buildings, which include: C&H Smelter, C&H Smelter Power Plant, Mineral House, Electric Shop, Acid Treating Plant, and the Electrolytic Plant.

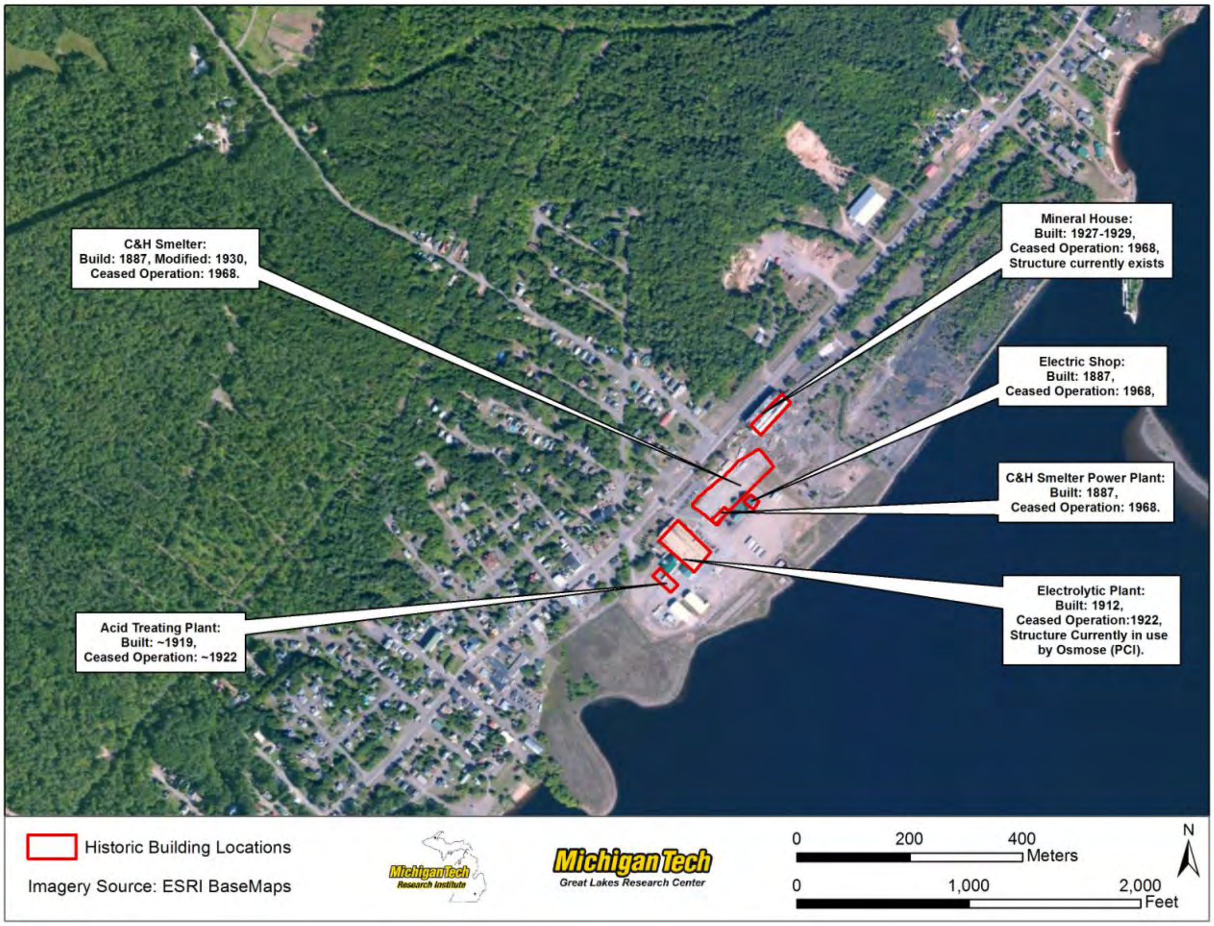


Figure 6: Similar to Figure 5, this map shows the various buildings listed in Figure 5. However, the underlying Sanborn data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

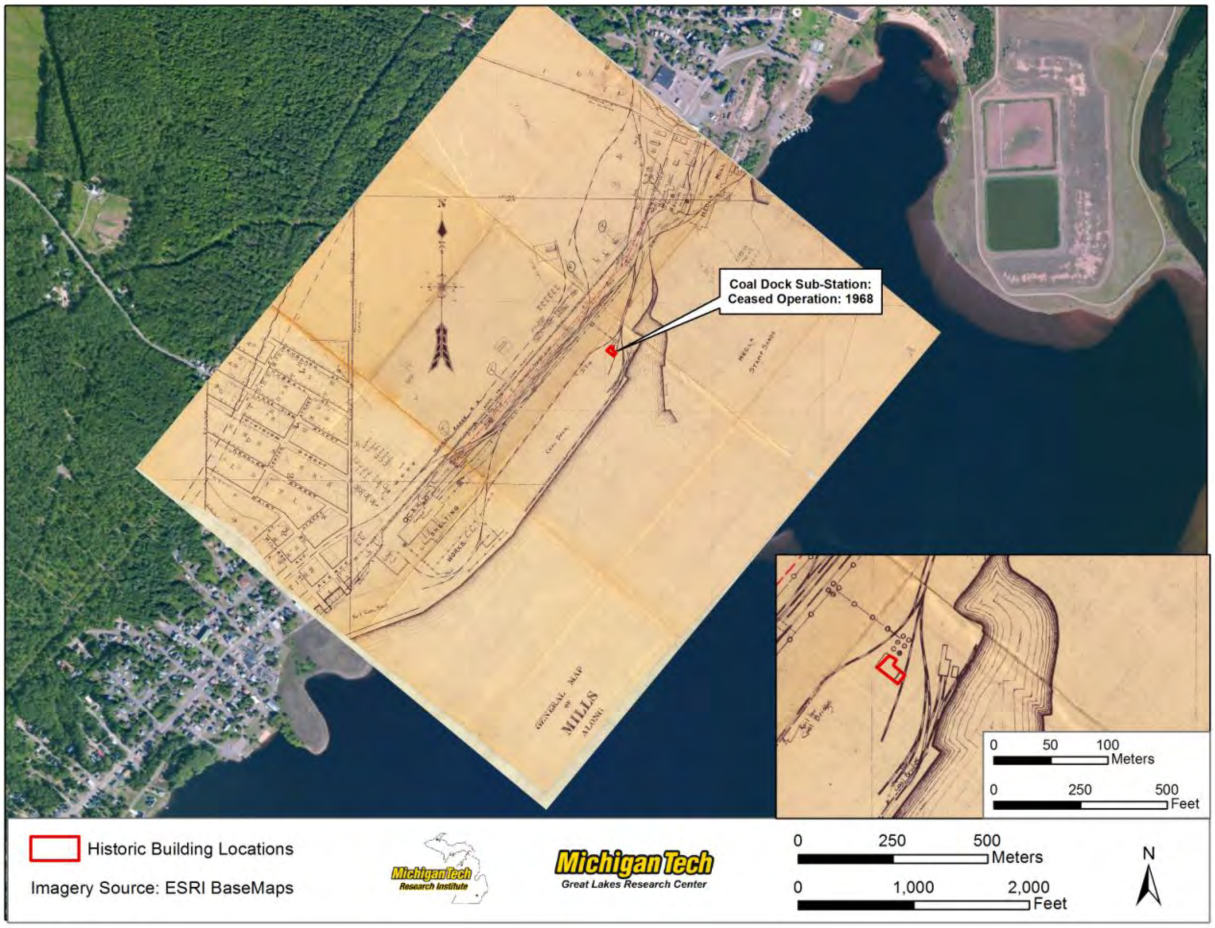


Figure 7: Here, the blueprint GeoTiff file "MS0023-138-13.tif" can be seen with the outline of the Coal Dock Sub-Station overlaid upon the data.

Figure 8: Similar to Figure 7, this map shows the outline of the Coal Dock Sub-Station. However, the underlying Blueprint data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

Figure9: Here, the blueprint GeoTiff file "MS0023-138-17-9003-georef.tif" can be seen with the outline of the C&H Smelting & Refining, Electric Shop, and partial coverage of the Mineral House overlaid upon the data.

Figure 10: Similar to Figure 9, this map shows the outline of the various buildings. However, the underlying Blueprint data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

Figure11: Here the blueprint GeoTiff file "MS005-6967-georef.tif" can be seen with the outline of the Coal Dock Sub-Station overlaid upon the data.

Figure 12: Similar to Figure 11, this map shows the outline of the Coal Dock Sub-Station. However, the underlying Blueprint data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

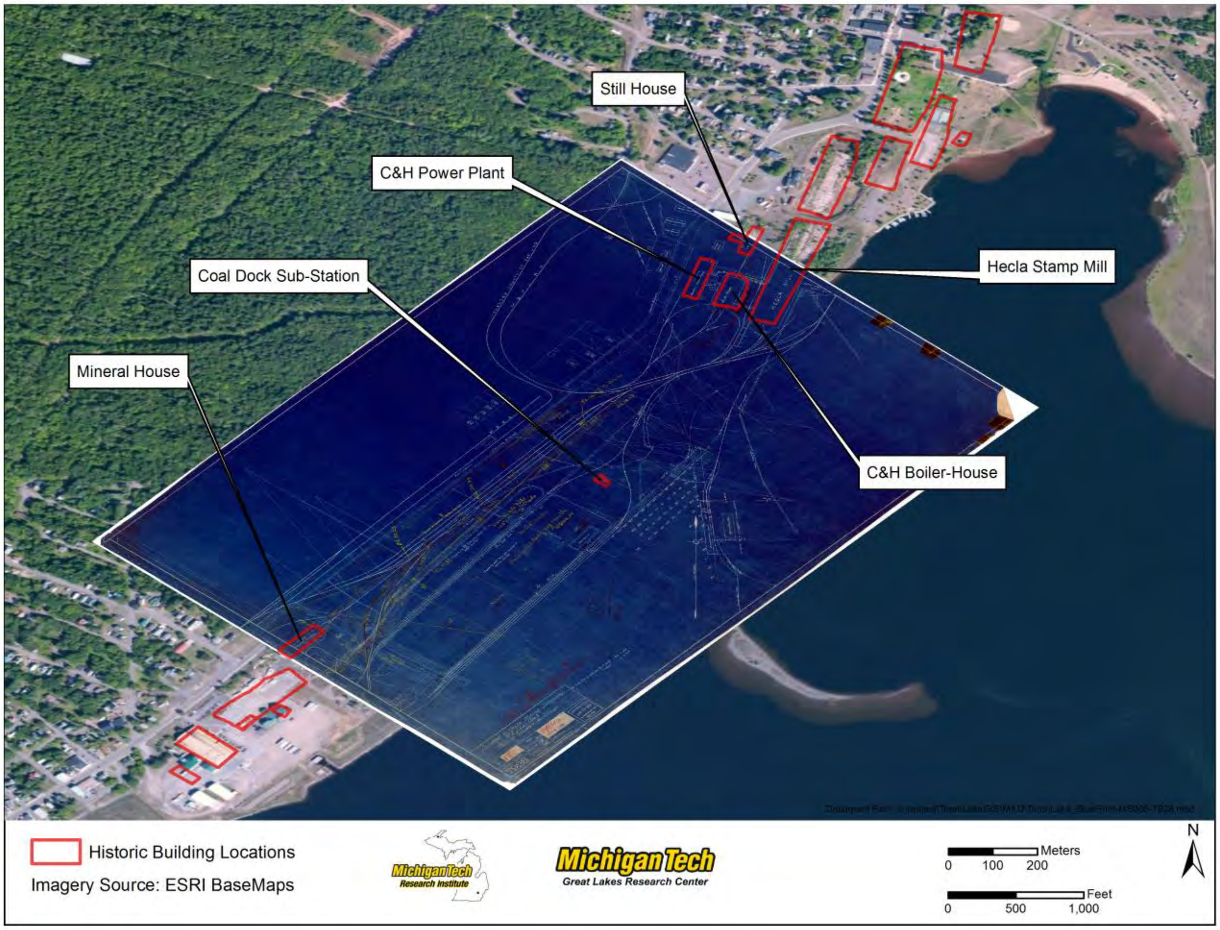


Figure13: Here the blueprint GeoTiff file "MS005-7928-georef.tif" can be seen with the outline of the Coal Dock Sub-Station, Mineral House, C&H Power Plant, C&H Boiler House, Still House and the Hecla Stamp Mill overlaid upon the data.

Figure 14: Similar to Figure 13, this map shows the outline of the various buildings. However, the underlying Blueprint data has been removed to show modern aerial imagery as provided by the ESRI ArcGIS Company.

MTRI also shared another set of GIS-ready data with MDEQ and the Weston Consulting Company. The file, titled "C_and_H_Historic_Buildings.shp," is a GIS shapefile data set and was derived from existing data. This shapefile was used to in each of the above figures as the "Historic Building Locations" layer, which are displayed as red polygons. This dataset contains an associated description table, known as an attribute table, which can be used in most GIS software packages. The table contains important information about each of these buildings, such as the date the buildings were erected, dates of new activity or products, and date of demolition or production stoppage. *Figure 9* is an example of these data.

Table

Buildings_with_attributed_data

Name	Build_Date	Cease_Date	Mod_Date	Sanborn_yr	Notes
Houghton County Electric Light & Power	1890 - 1902	1947 - 1969	Still Existing as storage facility	1917, 1928, 1935	NA
C&H Flotation Plant	1819	1953	1919-extension	1928	1916-flotation experiments, 1917-end experiments, 1918/1919-treat majority of slimes fror
C&H Leaching Plant	1914-1915	1968	NA	1917, 1928	1916-Processing began in July, 1931-not operational, 1935-operation resumes, 1942 leac

Figure 9: Here is an example of the attributed information that accompanies the shapefile that MTRI delivered to MDEQ and Weston. Some of the information includes the year of construction, demolition, and other important dates such as changes in production or machinery.

In addition to this GIS-ready file, MTRI provided a Microsoft Excel file, which contains all of the information that can be found in the attribute table mentioned previously. This Excel file is for use outside of GIS software. The Excel file is titled "Phase1_Building_Details_and_Dates_LakeLinden_Hubbell.xlsx"

All of these products described above can be found on the MTRI , File Transfer Protocol (FTP) website, which can be found by cutting and pasting the follow address into any web-browser:

ftp://ftp.mtri.org/pub/Torch_Lake_GIS/Revised_Maps_and_BluePrints/

These data will also be shared directly with MDEQ on a Compact Disc.

3.2 – Blueprints and Sanborn Files

In addition to the GIS data layers and maps, we will also be delivering separate Blueprint and Sanborn files for use outside of GIS software. These files will include all of the previously mentioned Sanborns and Blueprints, but will also include all of the original files that have been shared with MDEQ and Weston Solutions Inc. The following list will breakdown the file name; the buildings which are located within each file (if known) and the corresponding figure number found below.

Sanborn Files

1. File Name: 1928LakeLindenAug1928Sheet7b_CoElec.tif;
   Building(s) Located: Houghton County Electric Light and Power
   Figure 15

2. File Name: 1928LakeLindenAug1928Sheet8.tif
   Building(s) Located: C&H Flotation Plant, Sub-Station, C&H Leaching Plant, C&H Regrinding Plant No. 1, C&H Regrinding Plant No. 2, Calumet Stamp Mill, Hecla Stamp Mill, Still House, C&H Boiler House, C&H Power Plant
   Figure 16

3. File Name: 1928LakeLindenAug1928Sheet1index_HubbellTamarackNorth.tif
   Building(s) Located: Mineral House, Electric Shop, C&H Smelter, C&H Smelter Power Plant, Electrolytic Plant, and Acid Treating Plant.
   Figure 17

4. File Name: 1935sanborn_Weston 20101207 Power Plant SArpt.tif
   Building(s) Located: Calumet Stamp Mill, Still House, Electric Shop, Hecla Stamp Mill, Regrinding Plant No. 1, Regrinding Plant No. 2, Leaching Plant, Flotation Plant
   Figure 18

Blueprint Files

1. File Name: MS002-138-13-millsmap-001.tif
   Building(s) Located: Coal Dock Sub-Station
   Figure 19

2. File Name: MS002-138-17-900.tif
   Building(s) Located: C&H Smelting, Electric Shop, and Mineral House
   Figure 20

3. File Name: MS005-6967.tif
   Building(s) Located: Coal Dock Sub-Station
   Figure 21

4. File Name: MS005-7928.tif
   Building(s) Located: Hecla Stamp Mill, Still House, C&H Power Plant, C&H Boiler-House, Coal Dock Sub-Station, Mineral House
   Figure 22

5. File Name: MS005-9654.tif
   Building(s) Located: Mutual Pump Station, Tamarack Reclamation Sub-Station, Ahmeek Mill Power Plant, Ahmeek Pump House, Coal Dock Sub-Station, Smelting Works, Lake Linden Power Plant, Regrinding Plant No. 2 Sub-Station, Still House, Calumat Sub-Station, #1N. Kearsarge Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Cliff Sub-Station, Phoenix Sub-Station, Tamarack #5 Sub-Station, Tamarack Water Works, and Lake Superior Water Works.
   Figure 23

6. File Name: MS005-9966.tif
   Building(s) Located: Lake Linden Power Plant, Centennial Sub-Station, Calumet Sub-Station, #2 Ahmeek Sub-Station , #3&4 Ahmeek Sub-Station, Central Sub-Station, #1 Iroquois Sub-Station, #3 Allouez Sub-Station, #5 Tamarack Sub-Station, Tamarack Water Works, C&H Water Works
   Figure 24

7. File Name: MS005-11461.tif
   Building(s) Located: Ahmeek Power Plant, Smelter Coal Dock, Lake Linden Power Plant, Regrinding Plant #2, Calumet Sub-Station, Centennial Sub-Station, #3 Allouez Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Iroquois Sub-Station, Tamarack Water Works, and C&H Water Works
   Figure 25

8. File Name: MS005-12307.tif
   Building(s) Located: Quincy Booster Pump Station, Tamarack Reclamation, Ahmeek Power Plant, Coal Dock, Smelter, Regrinding Plant No. 2, Lake Linden Power Plant, #2 Centennial Sub-Station, #3 Centennial Sub-Station, #6 Centennial Sub-Station, #4 N. Kearsarge Sub-Station, #3 Allouez Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Iroquois Sub-Station, #2 Seneca Sub-Station
   Figure 26

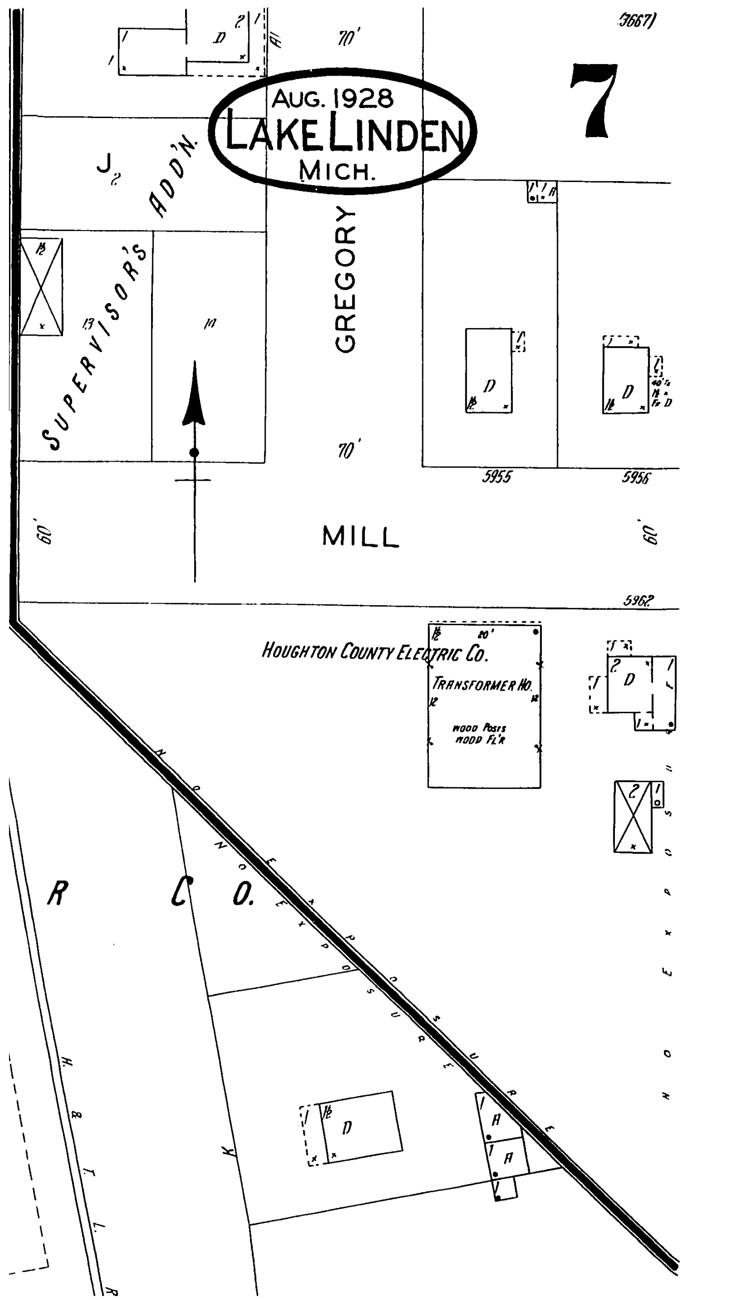


Figure 15: Here is the Original Sanborn file "1928LakeLindenAug1928Sheet7b_CoElec.tif" showing the Houghton County Electric Light and Power building.

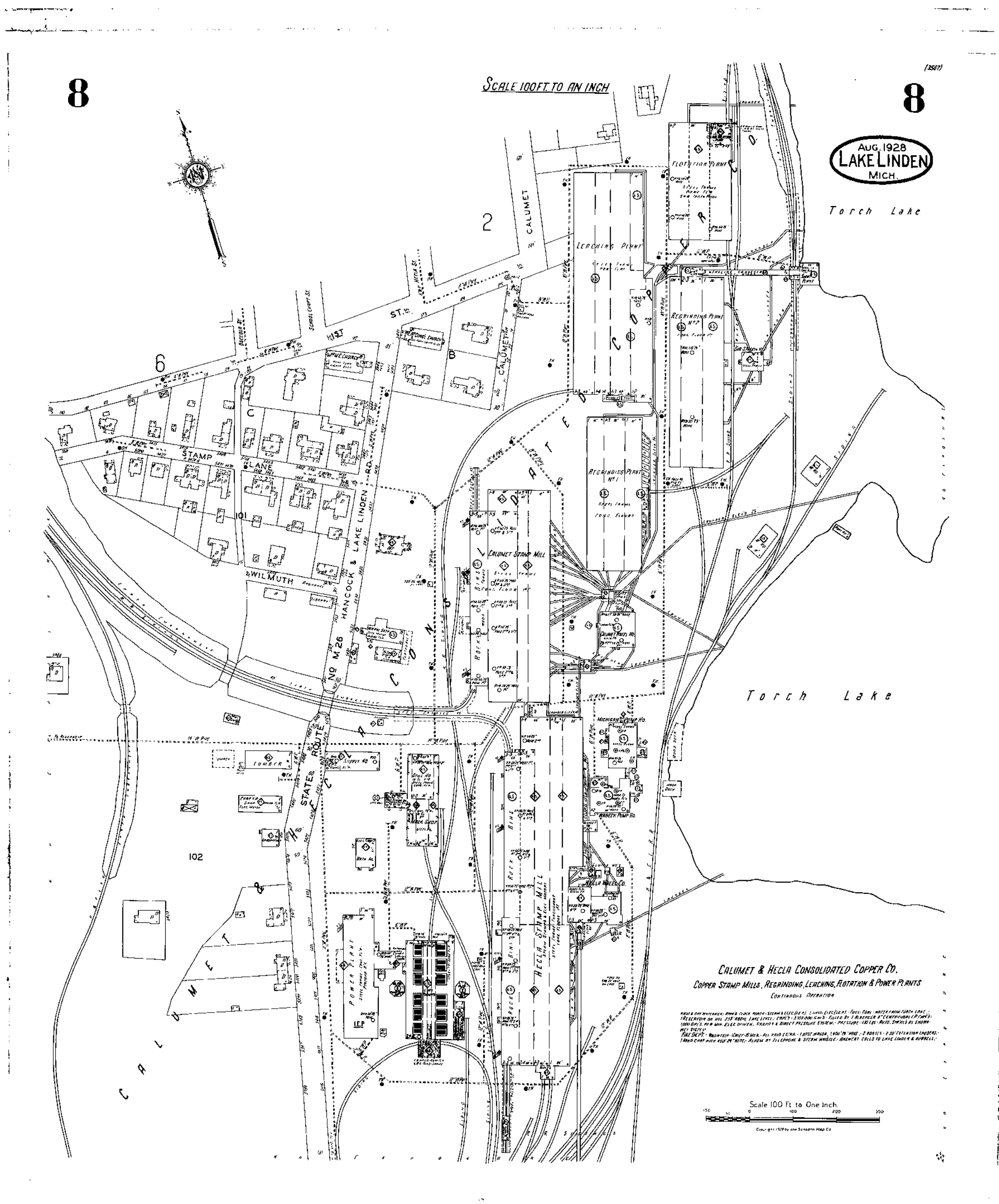


Figure 16: The original Sanborn file "1928LakeLindenAug1928Sheet8.tif" provided here covers the locations of the C&H Flotation Plant, Sub-Station, C&H Leaching Plant, C&H Regrinding Plant No. 1, C&H Regrinding Plant No. 2, Calumet Stamp Mill, Hecla Stamp Mill, Still House, C&H Boiler House, C&H Power Plant buildings.

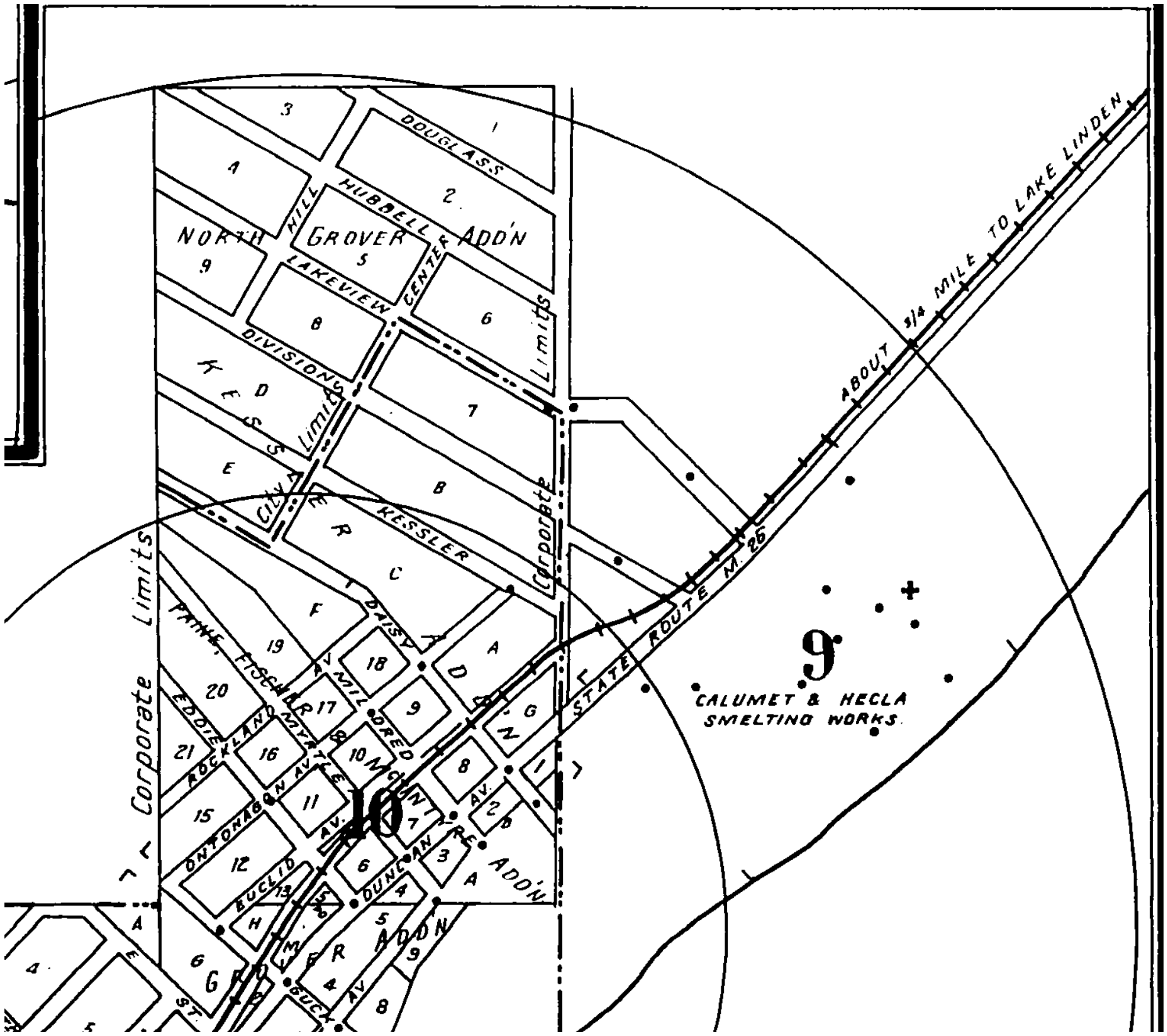


Figure 17: The original Sanborn file "1928LakeLindenAug1928Sheet1index_HubbellTamarackNorth.tif" here covers the locations of the Mineral House, Electric Shop, C&H Smelter, C&H Smelter Power Plant, Electrolytic Plant, and Acid Treating Plant buildings.

1935 Certified Sanborn Map

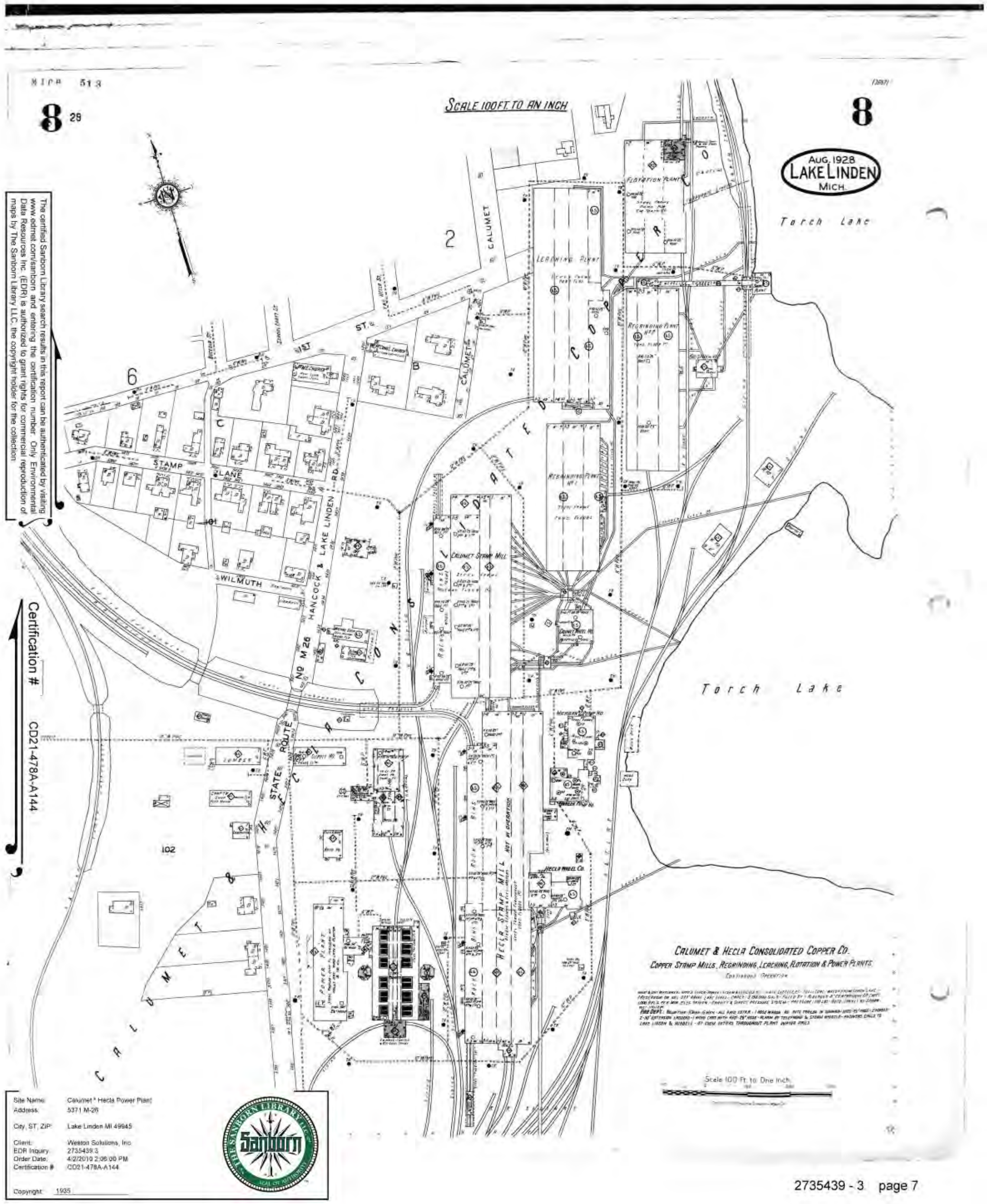


Figure 18: The original Sanborn file "1935Sanborn_Weston 20101207 Power Plant SArpt.tif" shown above contains the locations of the Calumet Stamp Mill, Still House, Electric Shop, Hecla Stamp Mill, Regrinding Plant No. 1, Regrinding Plant No. 2, Leaching Plant, Flotation Plant buildings.

Figure 19: This original blueprint file "MS002-138-13-millsmap-001.tif" contains diagrams of infrastructure and other buildings, including the Coal Dock Sub-Station.

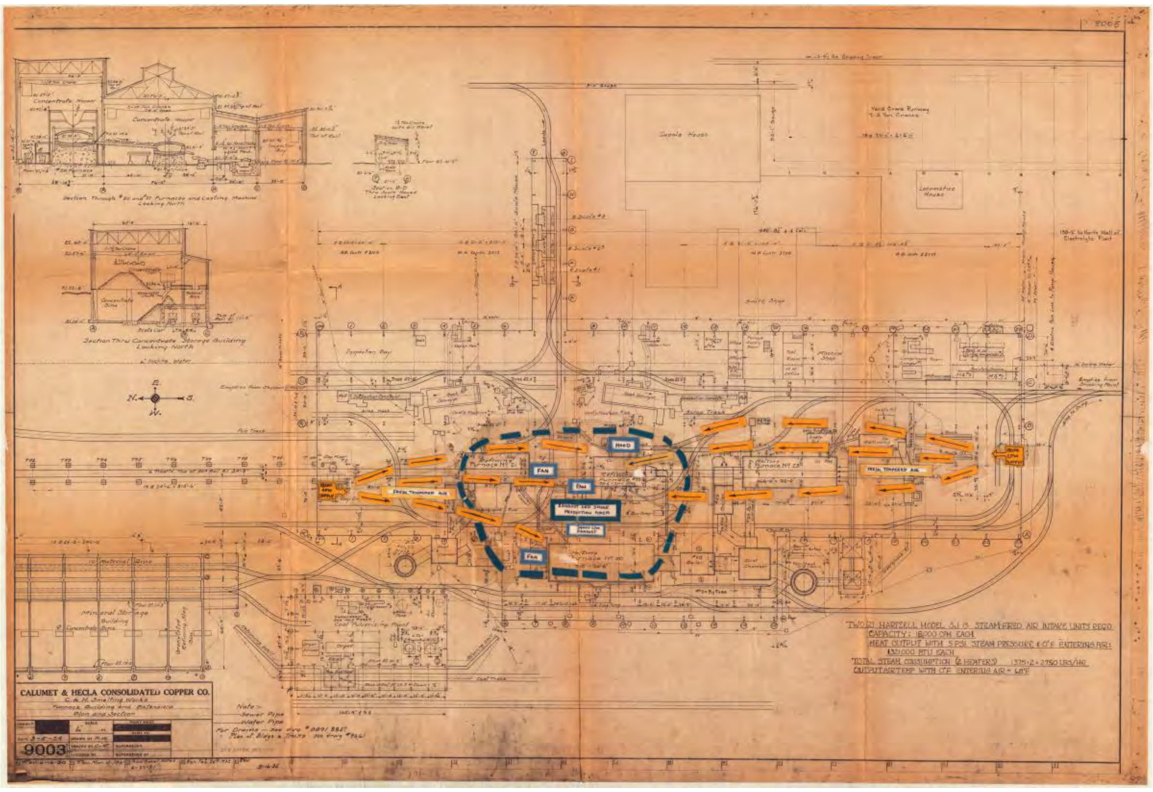


Figure 20: This original blueprint file "MS002-138-17-900.tif" shows the locations of the C&H Smelting, Electric Shop, and Mineral House buildings along with other infrastructure.

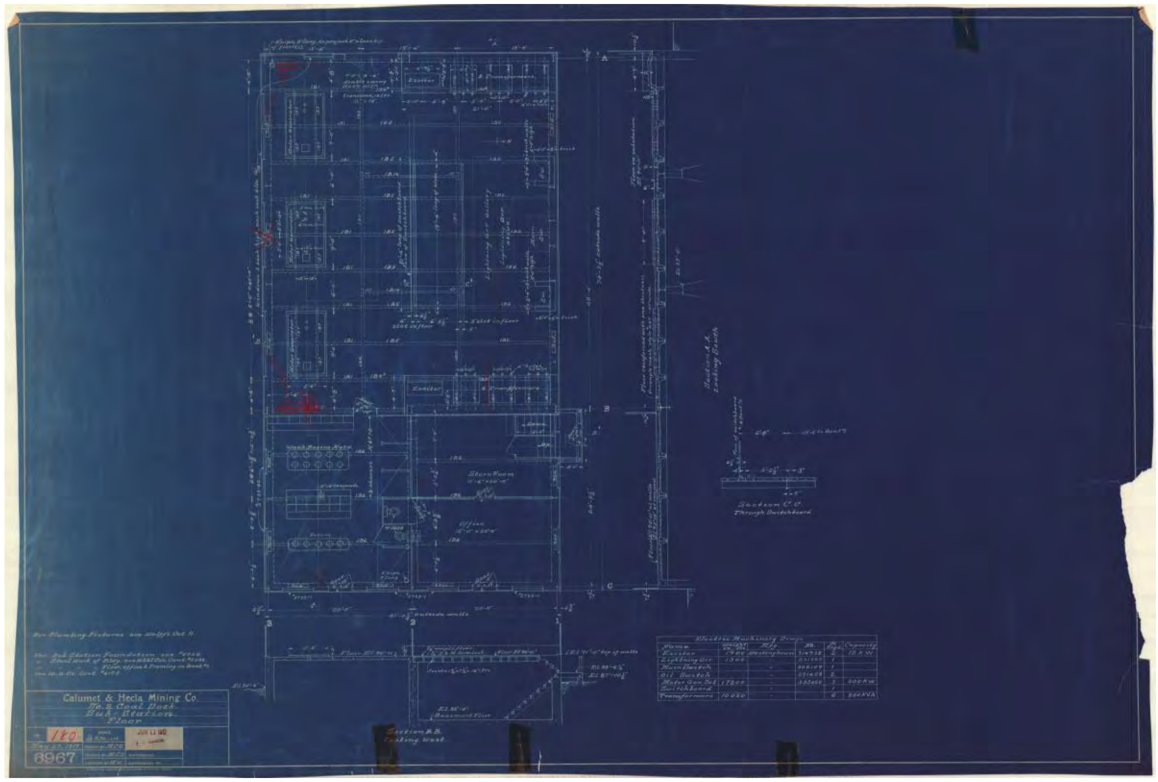


Figure 21: This original blueprint file "MS005-6967.tif" contains the schematics of the Coal Dock Sub-Station.

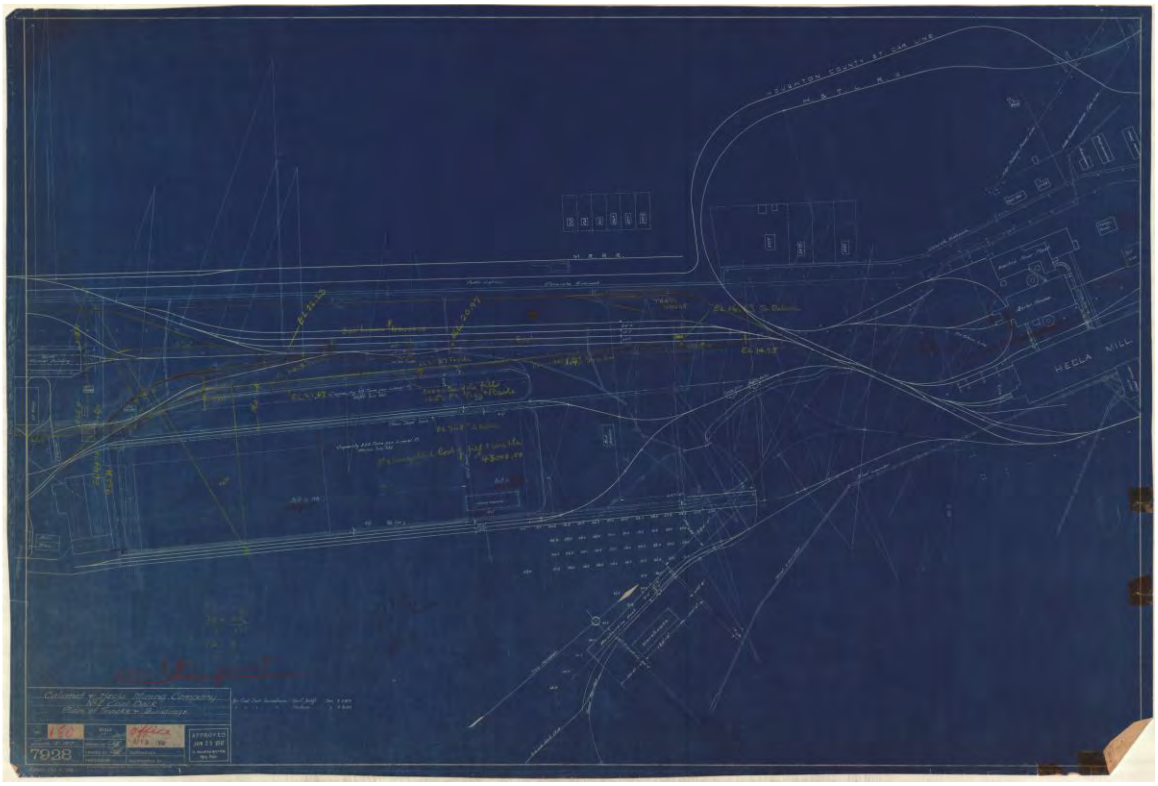


Figure 22: The original blueprint file "MS005-7928.tif" here contains schematics for the Hecla Stamp Mill, Still House, C&H Power Plant, C&H Boiler House, Coal Dock Sub-Station, and Mineral House buildings.

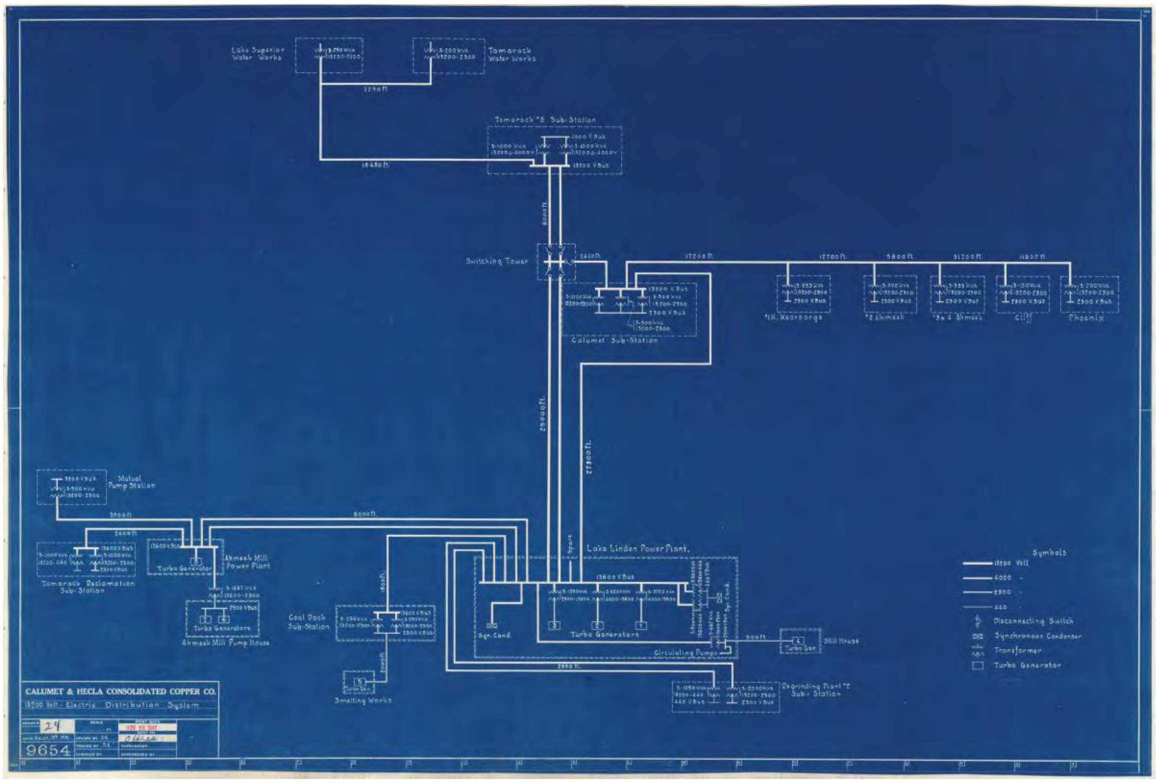


Figure 23: The original blueprint file "MS005-9654.tif" here shows the electrical diagrams between the following buildings; Mutual Pump Station, Tamarack Reclamation Sub- Station, Ahmeek Mill Power Plant, Ahmeek Pump House, Coal Dock Sub-Station, Smelting Works, Lake Linden Power Plant, Regrinding Plant No. 2 Sub-Station, Still House, Calumat Sub-Station, #1N. Kearsarge Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Cliff Sub-Station, Phoenix Sub-Station, Tamarack #5 Sub-Station, Tamarack Water Works, and Lake Superior Water Works.

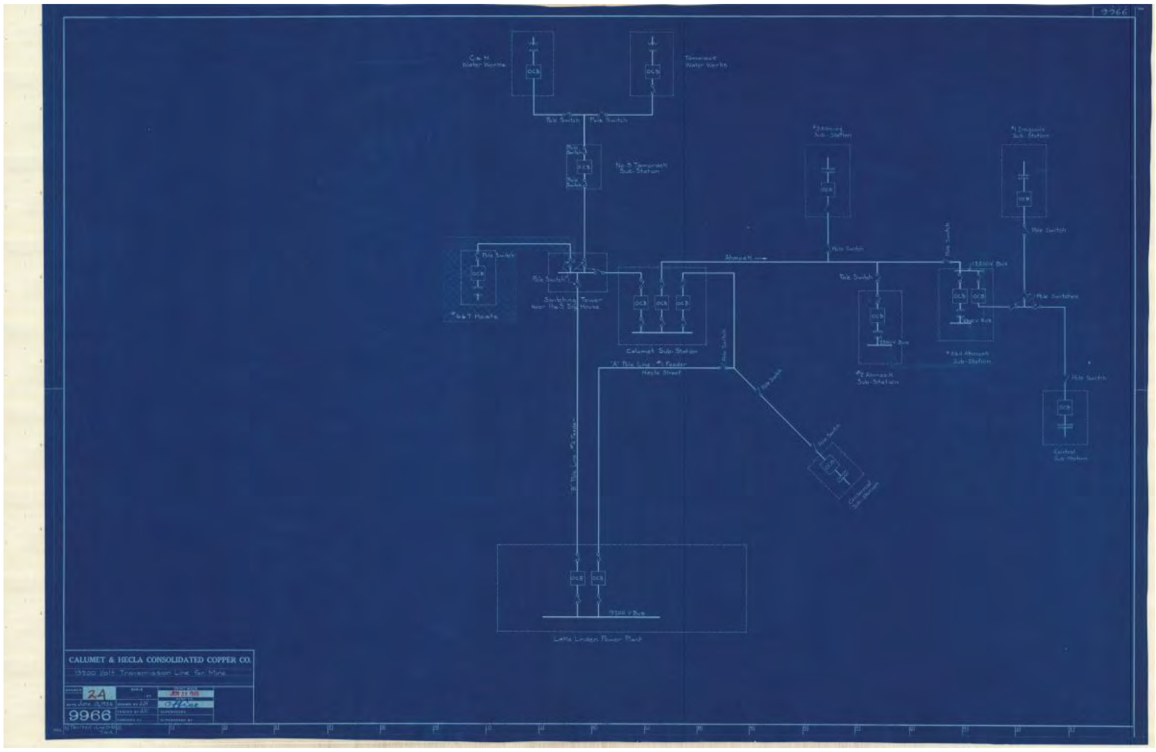


Figure 24: The original blueprint file "MS005-9966.tif" here shows more electrical schematics for the following buildings; Lake Linden Power Plant, Centennial Sub-Station, Calumet Sub-Station, #2 Ahmeek Sub-Station , #3&4 Ahmeek Sub-Station, Central Sub-Station, #1 Iroquois Sub-Station, #3 Allouez Sub-Station, #5 Tamarack Sub-Station, Tamarack Water Works, C&H Water Works.

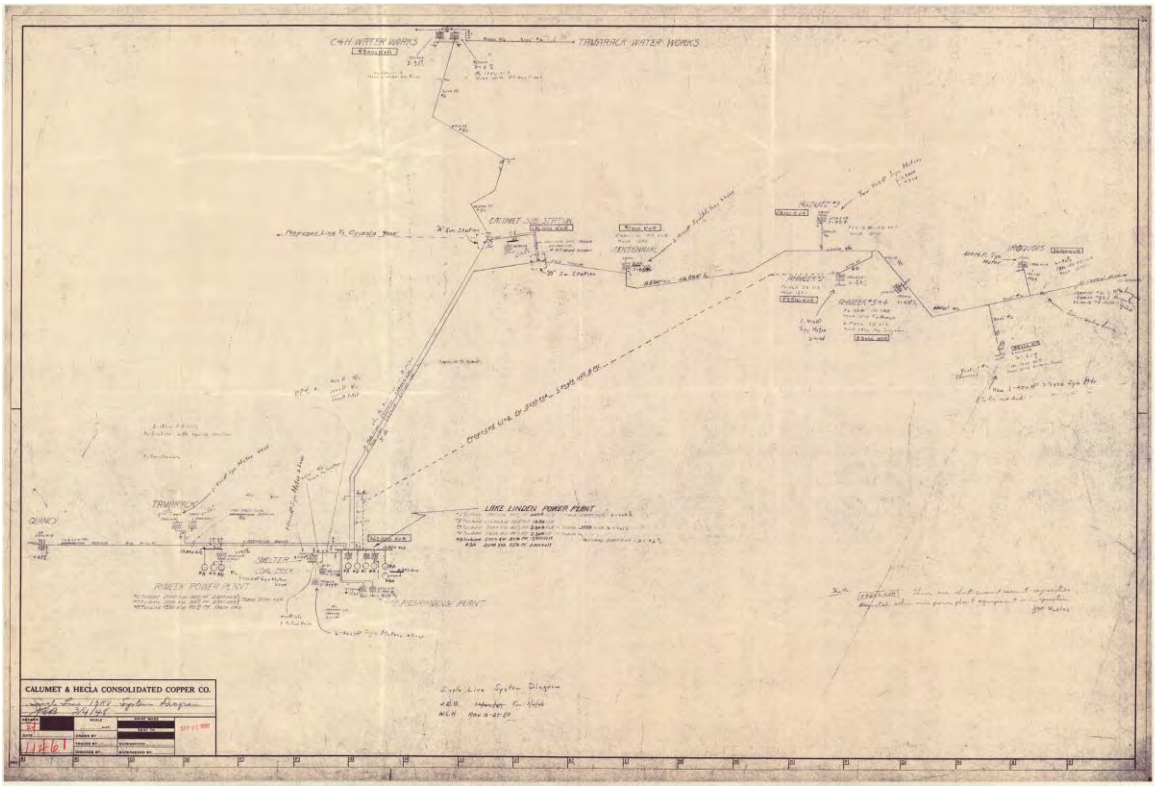


Figure 25: The original blueprint file "MS005-11461.tif" above, shows diagrams between the following buildings; Ahmeek Power Plant, Smelter Coal Dock, Lake Linden Power Plant, Regrinding Plant #2, Calumet Sub-Station, Centennial Sub-Station, #3 Allouez Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Iroquois Sub-Station, Tamarack Water Works, and C&H Water Works.

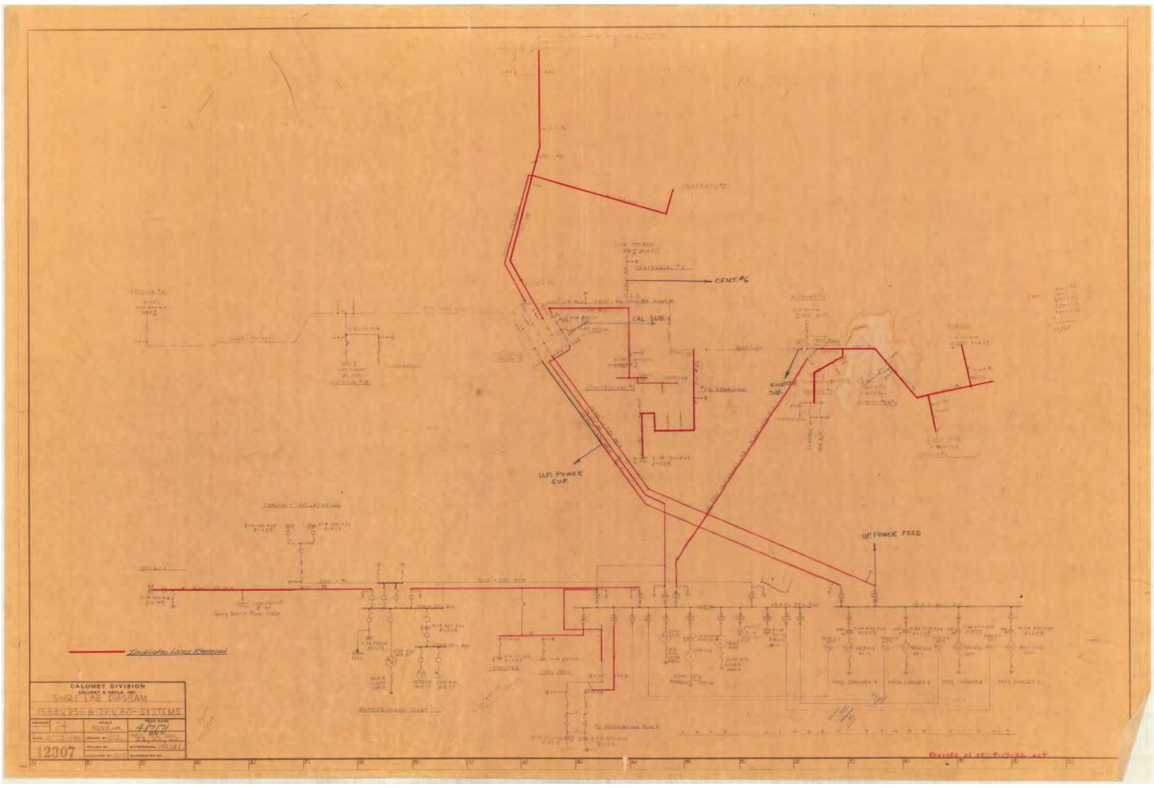


Figure 26: The original blueprint file "MS005-12307.tif" above shows more schematics between the following buildings; Quincy Booster Pump Station, Tamarack Reclamation, Ahmeek Power Plant, Coal Dock, Smelter, Regrinding Plant No. 2, Lake Linden Power Plant, #2 Centennial Sub-Station, #3 Centennial Sub-Station, #6 Centennial Sub-Station, #4 N. Kearsarge Sub-Station, #3 Allouez Sub-Station, #2 Ahmeek Sub-Station, #3&4 Ahmeek Sub-Station, Iroquois Sub-Station, #2 Seneca Sub-Station.

To summarize section 3, MTRI has produced a series of GIS-ready files which include Sanborn and blueprint GeoTiffs; as well as additional GIS-ready file which shows the outlines of each of the 18 buildings along with a timeline of important dates. To supplement these GIS data, we are sharing maps with all the GIS data overlaid upon them. These GIS data and maps are available on the accompanying Compact Disc and are in a folder titled "GIS." The GIS data will be in a sub-folder titled "Data" and the maps will be in a separate folder titled "Maps." As previously described we also included a Microsoft Excel document, which contains all the important dates of the 18 buildings for use outside of GIS workstations. This Excel file is also available on the Compact Disc

In addition to these GIS data and maps, we are also including all of the original Sanborn and blueprints for use outside of GIS workstations. These original files are on the Compact Disc and can be found separate folders titled "Sanborn" and "Blueprints" respectively.

Section 4: SUPPORTING DOCUMENTATION

Phase 1: North End of Torch Lake to Hubbell Beach

4.1 – Annotated Bibliography

Annotated Bibliography of Sources on Lake Superior Copper Milling/Refining and Calumet & Hecla Facilities

The sources listed below were systematically consulted for information on C&H Torch Lake facilities and the milling and metallurgical processes for refining copper. They provide critical information for anyone continuing to research the industrial history of the Torch Lake waterfront. Because MTU Archives has an extensive map collection, a separate annotated bibliography is provided.

(1.) Published sources

Benedict, C. Harry. *Red Metal: The Calumet and Hecla Story.* 1952.

The history of C&H, written by the engineer who helped developed some of the major milling and refining processes along Torch Lake.

Benedict C. Harry. *Lake Superior Milling Practice: A Technical History of a Century of Copper Milling.* 1955.

A valuable technical treatise of the major milling and refining processes (including flotation and leaching) utilized in the Lake Superior copper mines. Provides a good historical account and detailed description of the development of innovative methods in which mining engineer Benedict participated.

Stevens, Horace J. *Copper Handbook.* 1900-1913. Continued as the *Mines Handbook* to 1931.

Provides a good reference to the major changes in processes and facilities by company (C&H, Quincy, Copper Range, and earlier companies absorbed by these three firms. Draws heavily upon company annual reports and news accounts.

(2.) Professional journals for mining engineers (found in MTU Van Pelt Library, general collection)

Engineering and Mining Journal (1918-1940)

Engineers from C&H regularly wrote articles on developments in copper milling, smelting, and reclamation processes. To date articles were collected on all C&H facilities from 1918 to 1940—the most active period in milling, leaching, flotation, and refining innovation at C&H. Most of the processes developed in the 1910s and 1920s remained the same (with some modifications). These articles provide useful information for Phase 1 Buildings during this period:

"Ammonia Leaching of Calumet Tailings" (C.H. Benedict) July 14, 1917
"Developments in Lake Superior Milling" (C.H. Benedict) July 5, 1919
"The Use of Pulverized Coal" (H.R. Collins) August 17, 1918
"Six-Cent Copper from Calumet & Hecla Tailings" (C.H. Benedict) February 16, 1924

<u>*Mining Congress Journal.* October 1931. Series on C&H Facilities</u>
This issue provides a detailed overview of major facilities and processes at C&H in 1931.

"Transportation System and Coal Dock" (F.H. Haller)
"Electric Power Generation" (Rober McIntosh and A.L. Burgan)
"Milling" (C.H. Benedict)
"Flotation Practice" (Robert M. Haskell)
"Historical Development of Refining and Smelting Native Copper" (H.D. Conant)
"Smelting and Refining Native Copper" (HD Conant)
"Present Smelting" (E.R. Lovell and H.C. Kenny)

(3.) MTU Archives – Collections and Resources

<u>*Calumet and Hecla Mining Companies Collection. MS-022*</u>
This is an extensive collection of company records that includes correspondence, production records, financial accounts, maps, and blueprints. The finding aid (which is searchable by key word) can be located online at:
http://www.mtu.edu/library/archives/collections/documents/MS002_Hecla_and Calumet.pdf

<u>*C&H News and Views*</u>
A newsletter for employees printed by C&H between 1942 and 1949. It contains updates on new production and processing activities during this era, including substantial information on updates to facilities, new practices, and on topics not regularly found in other materials—e.g. water supply, transportation, etc. Is a good chronological source for the era after which the Steven's *Mine Handbook,* ceases to detail company activity. Call number in MTU Archives: F574.C2 C33 ARCH.

<u>*Calumet and Hecla Annual Reports*</u>
Provides an annual view of operations, new developments, financial information. Often recorded in more descriptive form in Steven's *Copper Handbook* and *Mine*

Handbook—yet worth utilizing to put developments in context of overall company financial picture and developments in non-Torch Lake facilities.

Daily Mining Gazette (DMG)
There is no index for the DMG and the paper must be read on microfilm in the MTU Archives. It is best utilized for specific time periods where known events would be recorded and described. For this project, the DMG is being read from 1968-1975 for information on the closing, dismantling, and disposal of C&H properties along Torch Lake. The C&H Collection is silent on this time period, with no records on what happened to individual facilities.

The Native Copper Times
A weekly newspaper published in Lake Linden, on microfilm in the MTU Archives. This paper is utilized for information on the 1968-1975 period, investigating the closing, dismantling, and disposal of buildings along Torch Lake.

4.2– Annotated Bibliography of Maps (MTU Archive)

Annotated Bibliography of Maps
Michigan Tech Archives & Copper Country Historical Collections,
Michigan Technological University, Michigan.

Section A – MTU Archives Map Collection

13200 Volt – Electric Distribution System. March 13, 1931. MS005-9654.

- Shows the C&H electric system originating from the Lake Linden power plant and spanning from Tamarack to Lake Linden, and Lake Superior Water Works to Phoenix.

13200 Volt Transmission Line for Mine. June 13, 1934. MS005-9966.

- Update of the C&H electric system originating from the Lake Linden power plant and traveling to Lake Superior and to the Central Mine.

Army Corps of Engineers. *Keweenaw Waterway Michigan including Torch Lake, Chart No. 944.*
Detroit, MI. March 15, 1905, October 7, 1908, April 18, 1917, September 1943, September 1964, January 1967, January 1970, and June 1973. Map Folders 20 j, 20 k,
20 l, and 20 m.

- These are a series of maps made by the Army Corps of Engineers showing the Keweenaw Waterway. Over time there is change in the waterfront including the transformation of company land and buildings as well as the filling up of the lake due to stamp sand deposits. By the 1970s the northernmost area of Torch Lake is almost all filled in, and the sunken dredge can be seen as a shipwreck from the 1964 map onward.

Board of County Road Commissioners Houghton Co. Engineer: T.A. Coon, Surveyor: W.L. Kaiser, Plotter: A. Sippola, August 1928. Map Folder 27 bb.

- This map shows the towns and companies along the coast of Torch Lake including Quincy, C & H, Osceola, Lake #2, Tamarack, Mellonsville, and Ahmeek.

Calumet and Hecla Consolidated Copper Company. *Trap Rock Valley Railroad, General Map*
Calumet and Vicinity. April 11, 1924. Map Folder 27 w.

- Shows the industrial coast including the Tamarack Mill, Ahmeek Mill, Hubbell,
C & H Smelter, C & H Stamp Mills, and Lake Linden.

Calumet & Hecla Mining Company No. 2 Coal Dock Plan of Tracks & Buildings. 1:100. June 18, 1917. MS005-7928.

- Shows the Torch Lake landscape from the north end of the Mineral Building to the Power Plant, Boiler House, and Hecla Mill.

Calumet & Hecla No. 2 Coal Dock Sub-Station Floor. ¼:1. May 23, 1917. MS005-6967.

- Blueprint of the Coal Dock Sub-Station.

Calumet & Hecla Smelting Works. 1:50. March 1, 1918. Map Folder 61 c.

- Shows the Electrolytic Plant and substation.

C & H Stamp Mills and Houses. 1:290. 1966. Map Folder 61 c.

- Shows the power plant and substations in relation to the C & H mill complex.

C&H Smelting Works. 1:20. March 5, 1929. MS002-138-17-9003.

- Blueprint of the Smelting Works including the smelter power plant, mineral storage building, and coal pulverizing plant.

General Map of Mills Along Torch Lake. 1:200. April 1, 1923. Map Folder 61 c.

- Shows the lakeshore from Osceola to Lake Linden.

Historic American Engineering Record. *Quincy Stamp Mill Location.* Eric Hansen, 1978. Map Folder 26 c.

- Gives the layout of the buildings in the Quincy Stamp Mill complex including the #1 and #2 pumps and boiler houses, tank house, oil house, and waste water pipe.

Map of Quincy Property and Vicinity. Map Folder 5 k.

- Shows when Quincy lands were purchased. On Torch Lake before 1891 and then in 1896 purchased from Mesnard & Pontiac companies.

sc eola, Lake N 2, Tamarack and Ahmeek Mill Sites. 1:600. March 1, 1918. Map Folder 61 c.

- Shows the power plant at Ahmeek and the substation.

Property at Mill, Ahmeek Mining Co. 1:100. April 1, 1923. Map Folder 61 c.

- Shows the Ahmeek Stamp Mill and the stamp sand lines.

Single Line 13KV System Diagram. March 4, 1948. MS005-11461.

- Update of the C&H electric system originating from the Lake Linden power plant and spanning from Mason to Lake Linden, and Lake Superior Water

Works to the Iroquois Mine, including line mergers with the Upper Peninsula Power Co.

Single Line Diagram. September 8, 1960. MS005-12307.

- Final update of the C&H electric system originating from the Lake Linden power plant and spanning from Mason to Lake Linden, and Lake Superior Water Works to the Iroquois Mine.

United States Department of the Interior Geological Survey. *Laurium, Mich.* 1948 Edition. 1946.

Map Folder 3 a.

- Topological map of Torch Lake and the communities of Mason, Hubbell, and Lake Linden as well as the Quincy mill complex.

Section B – MTU Archives Collection of Sanborn Fire Insurance Maps

Sanborn Map Company. *Lake Linden Mich.* New York, NY, September 1885. Map Folder 32 a.

- Map #1. Torch Lake City with the waterfront.
- Map #2. Laurent Jacques Wagon Works on the Torch Lake waterfront.

Sanborn Map Company. *Lake Linden Mich.* New York, NY, July 1888. Map Folder 32 a.

- Map #3. East side of Torch Lake with the Gregory Lumber Yard and the west side of Torch Lake with the Osceola Consolidated Mining Company's stamp mill.

Sanborn Map Company. *Lake Linden Mich.* 1:50. New York, NY, 1893. Map Folder 35 c.

- Map #1. 1:50. Armstrong and Thielman Planing Mill, C & H Dock and Mills, and the Peninsular Electric Light and Power Company (Lake Linden Station) including the coal trestle in the lake.
- Map #4. 1:50. Close-up of the Hecla Mill and the Calumet Mill.
- Map #6. 1:50. Shows the Gregory Sawmill and the Osceola Stamp Mill.

Sanborn Map Company. *Lake Linden Mich.* 1:50. New York, NY, 1900. Map Folder 35 c.

- Map #1. 1:50. Peninsular Electric Light and Power Company (including the coal tramway and two outbuildings) and parts of the C & H complex.
- Map #5. 1:50. Hecla Mill and Calumet Mill.
- Map #8. 1:50. Tamarack #1 and #2 mills and Osceola #1 and #2 mills.

- Map #9. 1:50. Centennial Mayflower and Old Colony Mining Company Owners as well as sawmills on the east side of Torch Lake.

Sanborn Map Company. *Hancock, Mich.* 1:50. New York, NY, November 1907. Map Folder
39 a.

- Map #21. Shows the Quincy Mining Company #1 and #2 stamp mills, coal shed, and the waste water pipe at the Torch Lake shoreline.

Sanborn Map Company. *Lake Linden Mich.* New York, NY, May 1908. Reel 27.

- Map #1. 1:50. Houghton County Electric Light Company and the coal tramway.
- Map #5. 1:50. C & H Power House near the Hecla Stamp Mill.

Sanborn Map Company. *Hancock Mich.* 1:50. New York, NY, August 1917. Map Folder 40 b.

- Map #18. Shows the Quincy Stamp Mill complex along the Torch Lake shoreline.

Sanborn Map Company. *Lake Linden Mich.* New York, NY, October 1917. Reel 27.

- Map #6. 1:50. C & H regrinding and leaching plants and the C & H substation.
- Map #7. 1:50. C & H Power House near the Hecla Stamp Mill.
- Map #8. 1:50. Houghton County Electric Light Company (shows no tramway and says "vacant").
- Map #13. 1:50. Mutual Water Light & Power Company near the Osceola Consolidated Mining Company buildings.
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Sanborn Map Company. *Lake Linden.* Chicago, IL, August 1928. Map Folder 32 b.

- Map #1. 1:600. Hubbell, Tamarack City, and Lake Linden, all owned by C & H.
- Map #7. 1:50. C & H Consolidated Copper Co. Mine Timber Sawing Mill (abandoned) and the Houghton County Electric Company (Transformer House).
- Map #8. 1:100. All C & H owned: power plant, both Hecla and Calumet stamp mills, regrinding plants #1 and #2, leaching plant, and the flotation plant with lime treatment.
- Map #9. 1:100. C & H Smelter and Refinery, Electrolytic Plant and testing house, and a power plant inside the smelter.
- Map #13. 1:50. C & H Consolidated Copper Co. Ahmeek Stamp Mills, including the transformer house.

- Map #14. 1:100. All C & H owned: Osceola, Lake #2, and Tamarack mills. Also the Elec. Sub Station and the Mutual Water, Power & Light Co. at the Tamarack Reclamation Plant.

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March 2014

4.3 – Journal Articles

4.3.1 – Mining Congress, 1931 **Flotation Practice**

Figure 1. 40 ft. thickeners in north flotation plant, Lake Linden.

Figure 2. Standard minerals separation flotation machines, north flotation plant, Lake Linden.

Figure 4. Fahrenwald flotation machines, Ahmeek mill.

FLOTATION

at the

By

FLOTATION was introduced at the Calumet & Hecla in 1918, at which time the first plant was put in operation to treat the fines from the stamps in both the Hecla and Calumet mills. The following year the North Flotation plant was completed and began handling the slimes from the reground lake sand together with that from the mills. Five years later two more flotation machines were added to those originally in this plant and the installation treating the primary slimes was then shut down.

The Tamarack reclamation plant was put in operation in 1925 to treat the old Tamarack sand. This plant is equipped with four 40-ft. diameter three-tray Dorr thickeners and two flotation machines to handle the slimes. Xanthate was adopted about this time in place of the coal tar oils theretofore used.

Three years later the Fahrenwald flotation machine was tried out and adopted for treating the amygdaloid sands which were too coarse for the old standard Minerals Separation machine to keep in suspension. Fahrenwald machines were installed at the Ahmeek, Isle Royale, and Lake Milling Company mills to treat the fines from the stamp together with the reground jig middling. Last year at the Ahmeek mill the practice of regrinding and floating the entire stamp product was begun.

CONGLOMERATE FLOTATION PRACTICE

The ores treated in the Calumet & Hecla stamp mills are of two very different types, (1) conglomerate and (2) amygdaloid. The former comes from the Calumet conglomerate and the latter from the Kearsarge and Osceola amygdaloid lodes. The conglomerate ore is noted for its hardness and carries a large part of its copper in such finely disseminated form that grinding through 200 mesh does not liberate it very thoroughly from the gangue, while on the amygdaloid, crushing through 48 mesh is sufficient to give a satisfactory extraction. Curves plated from the screen analyses of flotation tailings from these ores show this clearly.

As a consequence the conglomerate tailings are separated into plus 200 and minus 200 mesh products and only the later is floated, the coarser sand being leached with ammonia.

The north flotation plant handles the conglomerate slimes. The feed is derived mainly from two sources, (1) primary slime from the stamps, (2) secondary slime from the pebble mills in the regrinding plants. Most of the latter comes from the reclaimed sand from Torch Lake. About 1,000 tons per 24 hours of primary slime is treated and 1,400 tons of reground sand together with a highly variable amount of reclaimed slime from the lake. The pri-

* Metallurgist.

PRACTICE

Calumet & Hecla

Robert M. Haskell*

mary slime when treated by itself gives a decidedly higher tailing and richer concentrate than the reground sand (—200 mesh), but treating the combined product has given a better final result than handling them separately, partly because the feed is more steady and uniform in quality as well as in quantity.

The secondary slime which is derived from the leaching plant classification system comes into the plant at a density of approximately 2 percent solids and is divided between twelve 40-ft. diameter, three-tray Dorr thickeners, of both the open and connected types. (*Figure 1*). The thickened underflow at 25 percent solids is plugged off into an 8 in. direct connected Morris sand pump from the four thickeners nearest it and by means of 4 in. quadruplex diaphragm pumps from the others. To avoid the use of additional reagent feeders and obtain maximum conditioning, Xanthate, lime and pine oil are added at the feed pump. In addition to this feed, the slime from each head in the stamp mill is thickened in a 25 ft. diameter three-tray tank and the combined slime pumped over to the 8 in. feed pump which elevates the pulp to a distributor located between the flotation machines and is split between four of them. There are a total of six 16-cell, 24-in. standard Minerals Separation machines of the splash type, two usually being held as spares. (*Figure 2*). The feed enters the fourth cell, which is used for mixing only. From the remainder of the machine a rough concentrate is skimmed off which is elevated in a bucket elevator to the head of the machine and cleaned in the first three cells. This concentrate from all four machines is combined in another elevator and sent to the latter part of that machine nearest the concentrate thickener, for recleaning. This portion of the machine is blanked off from the rest and consists of five cells. The final concentrate flows by gravity to a 25-ft. diameter concentrate thickener. Two pneumatic machines of the Inspiration type, each consisting of seven cells 3 ft. by 4 ft. 6 in. in size, act as scavengers on the tailing from the Minerals Separation machines and make a low grade middling which returns to the feed pump. This operation lowers the tailings about .01 percent copper, although with the old coal tar reagents this saving was twice as great. The tailing flows to a second 8 in. pump which elevates it to the tailing bank in Torch Lake. This flow sheet is shown in figure 3. (B. P. 9602).

The underflow from the concentrate thickener at 60 percent solids is pumped by means of a 2 in. pressure diaphragm pump to an 8 ft. by 8 ft. Oliver filter. The filter cake carrying 18 percent moisture drops through a chute into a 50-ton hopper-bottom concentrate-car for shipment to the smelter.

The summary of operations at the North Flotation plant for the year 1930 follows:

Tons treated	625,760 tons
Copper recovered	5,427,060 lbs.
Assay feed	.527
Assay tailing	.105
Assay concentrate	35.55
Recovery	80.3

Costs

General		1.2c
Pumping and thickening		1.9c
Flotation:		
Attendance	.6c	
Power	1.3c	
Reagents	1.8c	
Repairs	.6c	4.3c
Royalty & Miscellaneous		1.1c
Total		8.5c

Reagents

In the beginning a crude pyridine oil obtained as a by-product from the manufacture of ammonia from certain by-product coke oven plants proved to be the best collector. A few gas-plant coal-tars and creosotes were satisfactory, more especially as stiffeners for the pyridine. Wood creosote together with some pine oil were used as frothers. The recovery was about 70 percent and grade of concentrate 25 to 30 percent copper. Xanthate increased 10 to 15 percent over previous results and the grade of concentrate to 35 to 40 percent copper. The reagent consumption is as follows:

Sodium xanthate	.06 lbs. per ton
Pine oil	.15 lbs. per ton
Lime	.30 lbs. per ton

The pine oil used is a mixture of 75 percent G. N. S. No. 5 and 25 percent Cleveland Cliffs No. 2 wood creosote at the feed pump. A. T. & T. No. 11, a destructively distilled pine oil, is used in place of wood creosote in the mixture for the drip cans on the machines. The drip cans are allowed to stand a day or so before use, which allows any sediment to settle out, thus preventing choke-up troubles.

The ores of this district are all more or less alkaline due to the presence of considerable lime and no sulfides. Even the lake water has a pH content of 7½ and the water in the flotation feed is usually about 8, so little alkali is needed. As the lime drops the iron oxide, which the wood creosote tends to float, and also decreases the pine oil required, a little of it is still used, although more than half of the total is added to the thickeners to aid in settling the slime. The lime is slacked in boiling water at 4 to 1 in an altered form of Pachuca tank with a coarse screen over the bottom, and then diluted to 10 to 1 before use. This gives a very high percentage of lime in soluble form. Diaphragm pumps are used for lime feeders.

Of all the different xanthates so far tried butyl-xanthate alone has proved superior to ethyl-xanthate, but the additional recovery is hardly enough to warrant the extra cost of reagent. Potassium-ethyl-xanthate was used at first, but has been superseded by sodium-xanthate, which is equally efficient. Amyl-xanthate is decidedly inferior. Phosphocresylic acid and some of its compounds are fairly satisfactory.

Preliminary work in the laboratory on amygdaloid ore indicated that soda-ash was better than lime, but after experimenting with it in various amounts in the mills its use was found to be unnecessary and it was discarded with no ill effects. The only reagents used are:

Sodium-ethyl-xanthate	.05 lbs. per ton
Pine oil	.18 lbs. per ton

G. N. S. No. 5 pine oil containing 3 percent A. T. & T. No. 11 pine oil is used. The oil consumption is higher here than in western practice, as it is impractical under local conditions to settle the mill tailings and reuse the water.

The ordinary pulley-type reagent feeder is used in the mills because it is simple, foolproof, and inexpensive. The summers are cool and without great temperature variation between day and night as in the southwest and the mills are steam-heated for about seven months in the year so that the viscosity of reagents is not changed sufficiently to alter the rate of oil feed and affect the flotation circuit.

Flotation on Amygdaloid

With the amygdaloids it is relatively easy to separate the copper from the gangue so that crushing through 48 mesh gives a final tailing assay of .02 to .05 percent, depending upon the lode and its grade.

Where regrinding and flotation of the entire stamp product is practiced the

Screen analysis of Conglomerate and Amygdaloid flotation tailings

Curve showing early recovery of copper

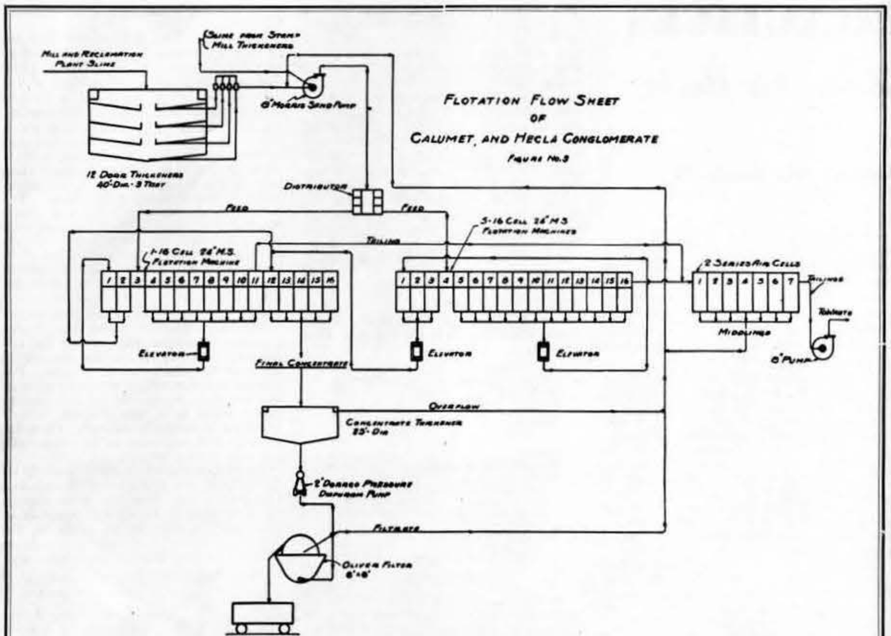

Figure 3

reagents are added to the ball-mill feed. The pulp density overflowing ball mill classifier is 40 percent solids, but this is lowered to 30 to 33 percent solids for flotation.

Of the 800 tons of rock stamped per head about 620 tons goes through the Fahrenwald machine (*Figure 4*) and most of the balance (primary slime overflow) goes to six 25-ft. diameter 3-tray thickeners in the mill basement, the thickened slime being elevated by means of six 4 in. diaphragm pumps to a 40-ft. Forrester flotation machine, which does very good work on this class of material.

The flotation circuit is simple. The feed enters the first cell of the Fahrenwald machine and a final concentrate is taken from the first two cells. From the remaining cells a rougher concentrate is made which flows by gravity into a side passage in the first cell directly over the impeller, thus avoiding the use of an elevator. This coarse concentrate averages nearly 60 percent copper, so retreatment is not necessary. Increasing the grade of concentrate much above this point increases the tailing loss materially. As regards operating conditions on the flotation machines it is advisable to carry a very high pulp level and comparatively small amount of froth for best results in saving the coarser particles of copper. Flotation of most of the copper is rapid, as the following curve shows:

Some of the heaviest particles lag behind and are recovered only in the final cells.

The flotation tailing flows to a 4-ft. 6-in. Dorr duplex classifier which makes an overflow averaging about .04 percent copper that amounts to 80 percent by weight of the tailing and is discarded. The sand product from the classifier is split between four Wilfley tables upon which a small amount of copper is recovered that has proven to be too heavy to float. The tables make a middling which is cleaned up on a finisher table, and the table tailings are combined with the classifier overflow as a final tailing to be pumped to the lake. The tables save about a pound of copper per ton treated, which lowers the flotation tailing approximately .01 percent copper. The table concentrate is high grade. As only a small amount of coarse sand is treated any change in the flotation circuit is magnified so that these tables make exceptionally good pilots.

The flotation concentrate is pumped to a drag classifier for removal of the coarse copper. The drag overflow flows to a 30-ft. traction thickener and the thickened product is elevated by means of a 2-in. pressure diaphragm-pump to the classifier discharge in order to wash the heavy copper into the filter. This latter is a 6 ft. by 4 ft. Dorrco fitted with a short belt conveyor for discharging the filter cake into a concentrate bin which can be emptied into 50-ton hopper-bottom cars for shipment to the smelter. The filter cake carries about 11 percent moisture and the dry assay is 55 to 60 percent copper.

The filter is run with an overflow which was at first returned to the concentrate thickener. This caused the slime to build up and make a dirty overflow. Later the filter overflow was returned to the Forrester flotation machine, resulting in a better grade of concentrate without raising the flotation tailing. The overflow of the concentrate thickener under these conditions is clear and remains so when operating conditions are normal.

Typical screen analyses of flotation feed and tailing and final tailing after tabling are as follows:

Mesh	Flot. Feed		Flot. Tailing		Final Tailing	
	Percent Wt.	Assay	Percent Wt.	Assay	Percent Wt.	Assay
+35	7.9	.50	8.4	.45	7.7	.23
+48	9.0	.50	10.0	.20	9.0	.12
+65	14.0	.52	14.7	.08	15.1	.06
+100	17.1	.46	17.1	.05	17.3	.06
+150	6.9	.42	5.6	.05	5.7	.05
+200	4.6	.44	3.1	.05	6.6	.04
−200	40.5	.19	41.1	.03	38.6	.03
Total	100.0	.37	100.0	.09	100.0	.07

Milling at the Calumet & Hecla Consolidation Copper Company

Figure 3. Calumet stamp mill, Lake Linden

Figure 4. No. 1 regrinding plant, Lake Linden

MILLING

at the Calumet & Hecla Consolidated Copper Company

By

C. H. Benedict*

THE present operating mills of the Calumet & Hecla Consolidated Copper Company† are all located along the borders of Torch Lake. The maximum rail haul from the mines does not exceed 10 miles so that transportation costs are low. The lake itself is some four miles long and from one to one and a half miles wide, is quite deep for an inland body of water and therefore affords ample storage for tailings, and is surrounded by gently sloping hills. It has been an ideal location for both the concentrator for current production and for the reclamation plants.

The mills are in three groups. At the north end of the lake, contiguous to the town of Lake Linden, are the original mills for treating conglomerate ore. These are known as the Calumet and the Hecla, respectively, of 11 and 17 stamp units each. These stamps when

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† The Conglomerate mills of the Calumet & Hecla Consolidated Copper Company have been described recently in "I. C. 6564 Department of Commerce," to which the interested reader may refer for such details as may not be given in this paper.

Figure 5. Leaching plant classifying system, Lake Linden

Figure 6. Sand leaching tanks in leaching plant, Lake Linden

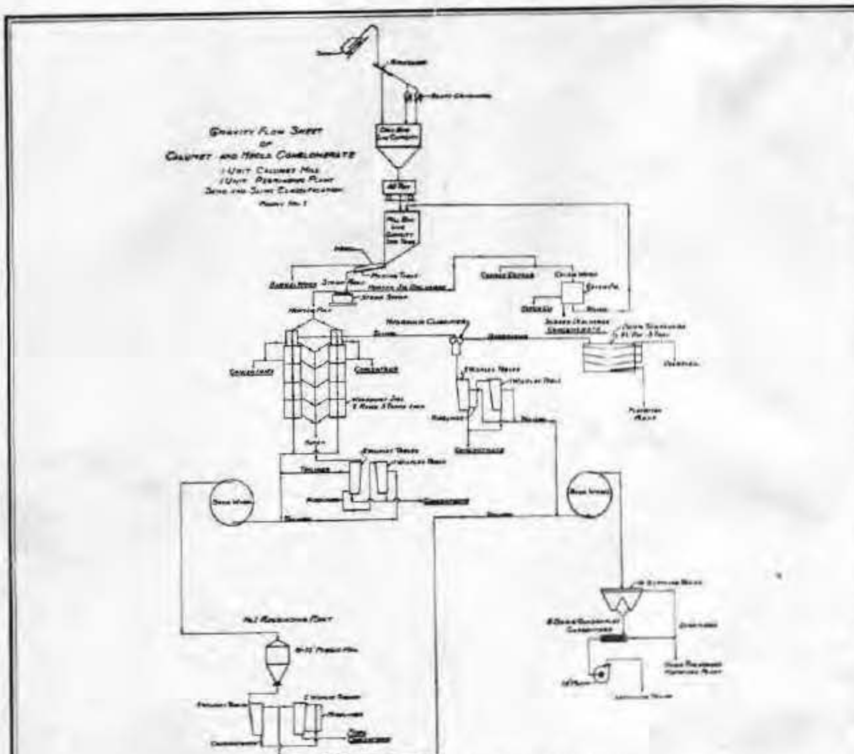

Figure 1. Gravity flow sheet of Calumet Conglomerate

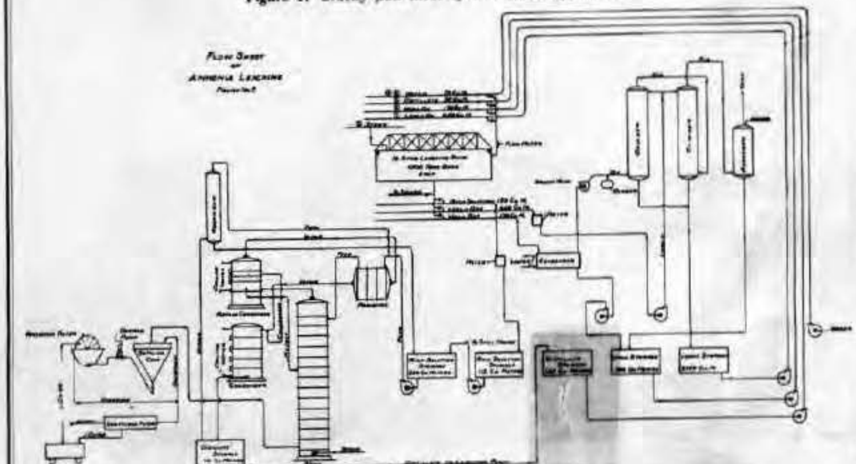

Figure 2. Flow sheet of ammonia leaching plant

CALUMET AND HECLA CONSOLIDATED COPPER COMPANY

operating on conglomerate have a daily capacity of some 350 tons and when operating on amygdaloid a capacity of 450 tons per 24 hours. The reclamation plant for treating old tailings is an integral part of this mill site, and some of the treatment plants, those used for leaching and flotation, treat both mine product and the corresponding product that has been dredged out of the lake. The coal docks and smelter adjoin these mills on the south and about half a mile south of these in turn is the principal mill of the district treating amygdaloid, the Ahmeek.

This Ahmeek mill consists of 8 stamp units of a total capacity of 6,500 tons daily, and at present this mill is treating practically all of the amygdaloid ore that is being produced under the current curtailed operating conditions. Half a mile south of the Ahmeek mill is another group consisting of the Tamarack reclamation plant and two stamp mills, the 7-unit Osceola mill and the 4-unit Lake mill. These latter two mills have a combined capacity of some 8,000 tons and are called upon for operation as the product increases beyond the capacity of the Ahmeek plant.

The conglomerate and amygdaloid ores, although similar in that native copper is the only economic mineral present, are so different in the physical nature of the gangue and in the distribution and size of copper particles that decided variations in metallurgical practice are necessary. Also the two amygdaloids that are worked at the present time by the Calumet & Hecla, namely, the Kearsarge and the Osceola, differ quite markedly not only in the richness of the ore but also in the nature of the distribution of the copper as regards size, so that here too there are variations in practice made necessary particularly by the prevailing low price for copper.

At the present time the only operating plant on conglomerate ore is the Calumet mill of the original Calumet & Hecla Mining Company which consists of 11 units. Even in this mill some amygdaloid is stamped, but the amount is insignificant and the units are not designed for this particular ore.

Nature of Ore

Copper occurs only as native metal with such occasional amounts of oxide and sulphide as to be inexpressible in percentage figures. The metallic particles range from the microscopic to masses of such size as to require special handling at the mines and these large masses are sent direct to the smelter under the local grading of "mine mass." The "mine mass" amounts to about .01 percent of the total copper in the conglomerate, whereas in the amygdaloid it may run as high as 9 percent. Of the product sent to the mill, some in turn is too coarse to enter the stamps without danger to the operating mechanism and this product is hand picked and sent to the smelter under the grade of "mill mass." This particular product constitutes only .2 percent of the total copper in the conglomerate but runs as high as 10 percent of the copper of the amygdaloid. These figures are sufficient to indicate reasons why the treatment of the conglomerate ore must differ very materially from that of the amygdaloid.

The variation between the Kearsarge and Osceola lodes as operated by this company is not as great as between the conglomerate and the amygdaloid. Such variations as are found necessary in the treatment of the amygdaloid is due more to the quality of the ore in point of richness than variations in the size of the copper particles. The Osceola lode will average about 20 lbs. by assay per ton stamped and has a larger percentage of material coarser than jig size than has the Kearsarge. The result of this is that the jig tailings (minus three-sixteenth inch) in the case of the Osceola are not sufficiently high in assay to warrant fine grinding at the present price of copper, whereas with the better quality Kearsarge all jig tailings are profitably reground in ball mills.

Lake Superior metallurgical practice differs from that of any other copper-producing district owing to two unique characteristics of the ore:

1. Native copper is present in all sizes from masses weighing many tons to microscopic sizes, and these particles resist reduction in size when once liberated.

2. The particles of native copper are tougher than the ore and hence are more resistant to abrasion.

Careful analysis of these two properties of the deposit accounts for much of the uniqueness of the metallurgical treatment of Lake Superior ores, a practice that has not been without criticism in the past by metallurgists of other districts, usually without sufficient knowledge of local conditions. It explains why the steam stamp has reigned supreme in the lake copper district for some 60 years in spite of occasional attempts to replace it, although the stamp has made no headway in other camps. It explains why stage crushing has not proved successful even in the days before flotation when such stage crushing was considered an absolute essential of good metallurgical practice in all other districts. It explains the prevalence of jigs and roughing tables in spite of their more recent abandonment in favor of all flotation in many camps. A piece of copper the size of the head or the fist or even of a pea presents rather a firm argument against a diminution in size by any of the known crushing machines.

Historical Development

Some stamps were used on Lake Superior in the sixties, just as soon as the mines began to develop any tonnage. Mechanically the efficiency was low and was so recognized. Later practice consisted of the use of a compound stamp which had a greater efficiency than the simple stamp. In all of the modern plants the exhaust steam from the stamps is used in low or mixed-pressure turbines for generating electricity, thereby obtaining an excellent final mechanical efficiency from the combined units.

Current practice calls for hand picking of large nuggets from the ore, preceding stamping. When a large piece of copper escapes the vigilance of the attendant and gets into the stamp it does no mechanical harm. It remains there, abrading slowly until such time as it may be necessary to open up the stamp in order to change a shoe. There have been times in the past when the presence of these copper nuggets, owing to rich ore, presented a problem. This was solved by the application some 30 years ago of a hydraulic discharge within the mortar. On the amygdaloid, in addition to the original 20 percent of mass, as high as 30 percent of the total copper of some lodes is obtained before the material is of a size of minus three-sixteenths inch at which jigging is practiced.

Before the introduction of the Wilfley table in 1898, the recovery of copper from the fine size or so-called slimes (a separation at about 60 mesh being the local term for slime) was very inefficient. Fortunately the value in these slimes was low because of the non-friable nature of the valuable mineral. The smelters in those days demanded a high grade product so that very little success attended attempts to save the values finer than 60 mesh by means of revolving tables. With the gradual displacement however of the revolving tables by Wilfleys, recovery became greater and there was some incentive to fine grinding. Chilean Mills were universally used for this purpose from about 1905 to 1915 and since that time the standard fine grinding unit of the district has been the Hardinge pebble or ball mill.

Calumet Conglomerate Milling

Of all the mines in the district, only the Calumet & Hecla is operating on conglomerate ore. This lode has been extraordinary in quality, and even after 60 years is the richest ore being mined on Lake Superior. It is well that it has been so for the metallurgical treatment of this material presents difficulties much greater than that of the amygdaloid. This is due not only to the distribution of much of its copper in fine sizes down to the microscopic, but also because of the hardness and toughness of the gangue.

The conglomerate consists chiefly of felsite, feldspar porphyry, and quartz porphyry, with some few amygdaloid boulders. In some parts the lode is made up largely of coarse to fine sand; in other portions it is a pebble conglomerate. The copper occurs chiefly as cementing material around the pebbles. There is some very fine copper within the pebbles, and the sand itself contains copper of microscopic fineness so that complete liberation of values is impossible. The ore has a hardness of 7, is very tough, and there are no fractures once the conglomerate is broken down. Comparative tests on resistance to crushing are difficult to obtain, but such independent work as has been done by outsiders indicates that the Calumet conglomerate resists crushing and particularly fine grinding more than any other known copper ore.

The ore has naturally a high abrasive action corresponding to the resistance to crushing as evidenced by the great wear of stamp shoes in stamping, of pebbles or balls in grinding, impellers and liners in pumping, etc. The chilled iron shoes stamping conglomerate have only one-tenth the life of corresponding shoes stamping Osceola amygdaloid.

The concentration of this conglomerate ore consists principally of four operations which were developed chronologically and are housed in four separate units as follows:

1. Calumet stamp mill containing the stamps, coarse jigs and coarse Wilfley table treatment. This unit was built originally in 1872 and has been added to and remodeled from time to time till 1904.

2. No. 1 regrinding plant containing

Figure 7. Ammonia solution pumps in leaching plant, Lake Linden

Figure 9. Preheaters in still house, Lake Linden

Figure 8. Ammonia still in still house, Lake Linden

Hardinge pebble mills and Wilfley tables for treatment of the reground sand and recovery of the liberated values. This was built as a Chilean mill plant in 1907, which mills were later replaced by Hardinge mills.

3. Leaching plant where ammonia leaching is practiced on the crystalline particles (plus 200 mesh). This plant was constructed in 1915.

4. The flotation plant for the recovery of the values from slimes, erected in 1918.

Figure No. 1 is a flow-sheet of the gravity practice as examplified by one unit of the Calumet mill (of which there are 11 units), one unit of the No. 1 regrinding plant (of which there are 12 units now operating) and sand and slime classification. *Figure No. 2* is a flow-sheet of the leaching plant. (B. P. 9602.)

CRUSHING AND GRAVITY CONCENTRATION

The ore as mined is crushed in the rock house to about 4 in. size by means of Blake crushers and transported to the mill in 40-ton cars. These are dumped into the mill bins which have a live capacity of about 200 tons, being sufficient to keep the stamps running ordinarily throughout the night. Intermediate crushing is entirely by means of Leavitt stamps, which is a single expansion stamp of rather complex design. The stroke of the stamp is 24 in., the weight of new shoe is about 725 lbs., the weight of moving parts about 6,000 lbs., and the horsepower developed is just under 200.

The stamp screens have 3/16 in. round openings punched in a plate 0.11 in. thick. The coarse copper is discharged from within the stamp by means of a Woodbury mortar jig which makes two products, a screen discharge of about 1½ in. nuggets and larger, and a hutch product of about 1 in. size. This jig is actuated by a plunger outside the mortar and is discharged intermittently.

The stamp product, all of it reduced to 3/16 in., is now classified into the so-called slime of about 60 mesh and the coarser sand for jigging and table treatment. For this purpose a Woodbury jig-classifier is used which makes four products:

1. Slimes at about 60 mesh.
2. Hutch product for table treatment.
3. Coarse copper concentrates.
4. Coarse and fine sand tailing.

This Woodbury classifier was developed at the Calumet & Hecla and is very effective for the purpose, although it is now being displaced to a great extent in the district by the Dorr classifier which makes only two products but eliminates dilution of the slime.

There are two lines of classifiers and jigs per stamp. (*Figure 1.*) The hutch product of the jigs is treated on Wilfley tables and the tailings of these Wilfleys along with the tailings of the jig go to the No. 1 regrinding plant for finer grinding. The slime separated out on the original slime classifier is thickened in 25-ft. diameter three-tray Dorr thickeners and treated by flotation.

The copper recovery in the original stamp mill is between 75 and 80 percent of the value of the ore, the rest of the recovery taking place in the so-called retreatment plants consisting of fine grinding, leaching and flotation. The concentrates are graded chiefly by size as follows:

Grade	Assay percent	Percent of Total copper
No. 0 Grade (⅜-inch)	91.50	3.75
No. 1 Grade (+10 mesh)	89.00	40.75
No. 2 Grade (−10 mesh)	57.00	55.50

These figures are for stamp mill concentrates only. Including fine grinding, leaching and flotation recoveries, figures are as follows:

Grade	Assay percent	Percent of Total copper
No. 0 Grade (⅜-inch)	91.50	3.75
No. 1 Grade (+10 mesh)	85.00	30.75
No. 2 Grade (−10 mesh)	55.00	47.75
Flotation (−100 mesh)	33.00	9.50
Leaching (solids)	32.00	8.25
	61.00	100.00

FINE GRINDING

The fine grinding units consisting of 8 ft. by 72 in. Hardinge mills, are run at a speed of 24 r. p. m., and are driven in units of three by 250 hp. motors. There are 24 of these mills in the No. 1 regrinding plant (*Figure 4*) with only half of them being operated at present. Each mill has capacity of about 110 tons per 24 hours, requires 90 hp. and is run open circuit at a dilution of about 25 percent solids. The mills are lined with old steel rails embedded in neat cement. Danish pebbles preferably 4 in. in size are used as the grinding medium. The pebble consumption is about 5 lbs. per ton of sand ground and as the pebbles cost about ¾ cent per lb. delivered at the plant, the total cost of grinding for pebbles is 4 cents per ton of sand. Steel balls have been tried and abandoned because of excessive cost, as the wear per ton of sand ground is almost as great with steel as with pebbles. This arises from the hardness of the ore and does not hold true for amygdaloids.

Figure 10. Vacuum and pressure filters in still house, Lake Linden

Figure 11. Twenty-inch suction pump in dredge, Lake Linden

The cost of this grinding per ton for the year 1930 is as follows:

General Expense		1.4c
Conveying and distribution		.5c
Grinding		12.2c
Attendance	.8c	
Power	7.2c	
Pebbles	3.1c	
Lining	.7c	
Other	.3c	
Washing		1.8c
Total		[illegible]

Following this grinding and table concentration all the product is classified into sands for ammonia leaching and slimes for flotation. (*Figure 5.*) This separation is roughly at 200 mesh although there is some 15 percent of minus 200 mesh material that goes to leaching and some 5 to 10 percent of plus 200 mesh that goes to flotation. It is quite possible to float copper of a much coarser size than this, but because of the enclosed copper in material even as small as minus 100 mesh the recovery by means of flotation is low at this size. Accordingly on conglomerate only the very fine sizes are treated by flotation, whereas with the amygdaloid flotation at 35 mesh is practiced.

The slimes from the fine grinding units are thickened in three-tray Dorr thickeners 40 ft. in diameter. After thickening, the products from the original stamp mill and that from the regrinding plant unit are combined in treatment by flotation. This flotation is described in a separate article in this same issue of THE MINING CONGRESS JOURNAL.

LEACHING

Sands are treated by means of ammonia leaching. This operation has been frequently described in detail in the technical press* and will be given but briefly here.

This process was developed at the Calumet & Hecla independently but concurrently with a similar development on oxidized ores by the Kennicott Copper Company. It has been used in a modified form also by the Bwana M'Kubwa Copper Company in Northern Rhodesia. Both the plants in Alaska and that in Rhodesia are now shut down so that this operation of the Calumet & Hecla represents the only copper ammonia leaching plant at present operated.

The equipment for dissolving copper from the sands consists primarily of 16 steel leaching tanks 54 ft. in diameter by 12 ft. high in two rows of eight each (*Figure 6.*), and 25 solution storage tanks with the necessary pumps (*Figure 7*) and piping for circulating solutions. In addition to these there are auxiliary devices such as oxydizing towers and condensing units. Regenerating the solvent and recovering the dissolved copper is effected by distillation.

The sand for the leaching tanks is all minus 28 mesh. All copper that can possibly be saved by gravity concentration has been extracted, and the remaining copper is chiefly attached to or included in the grains of sand. The average sizing will show 15 to 20 percent of minus 200-mesh material of which only a small portion is colloidal. The major portion of this colloidal material remaining after classification escapes from the main body of sand in the overflow of the leaching tanks during the filling operation.

The solvent employed is cupric ammonium carbonate. After distillation the return to the leaching cycle consists of ammonium carbonate, but losses of reagent during the process are made up by aqua ammonia which is carbonated in the plant in the same towers in which the solution is oxidized from the cuprous to the cupric state.

The chemistry of the process is simple. As native copper is the only valuable mineral present in the ore, advantage is taken of the two valences of copper in water solution to effect its oxidization and subsequent solution in the cuprous form. The first reaction is between native copper and cupric ammonium carbonate in an excess of ammonium carbonate to yield cuprous ammonium carbonate, weight for weight of copper. To use this copper ammonium carbonate as a new leaching solution it must be regenerated to the cupric condition by oxidizing it with air. This reaction between cuprous carbonate and oxygen takes place in the presence of ammonium carbonate and yields cupric ammonium carbonate which is now ready for the next leaching cycle.

After the leaching solution is partly or entirely saturated with copper by passing it through the ore, an amount equivalent to the copper dissolved from the sand is removed from the leaching cycle and is distilled to yield copper oxide, with the recovery of the ammonia and carbon dioxide as ammonium carbonate. This leaching cycle theoretically results in no loss of solvent, the only actual chemical consumed being the oxygen of the air which appears in the copper oxide in the final product.

The leaching tanks are in two rows. A crane travels over each row of tanks for handling removable tank covers, sand distributors, sand levelers, flushers, and other auxiliaries. As the tanks must be covered during leaching to prevent loss of ammonia by volatilization and to make it possible to live in the plant, all distributing and flushing apparatus must be removed instead of fixed to the building structure as it might be if open tanks could be used. The tank covers are of steel plate with top trusses which are supported on an encircling angle iron around the tank wall. A seal between the cover and the tank is made by a channel-iron on the cover projecting into an annular launder on the tank, which launder acts as an overflow carrier during the sand-filling stage and is filled with water during the leaching stage. This seal prevents the escape of ammonia around the edges of the cover and is the only joint necessary either during the leaching or the steam wash.

For filling the tanks a portable distributor of the Betters and Mein type is used. It is supported on the central shaft of the tank and revolves by its own reactance. The sand is carried throughout the length of the plant in a central launder, and connections are made from this central launder to the distributor by means of a portable launder. Gates in the central launder control the flow so that the sand is fed consecutively from tank to tank. The alternating tanks are on either side of the main central launder, and with two sets of portable launders and distributors there is no delay in filling while shifting from a full tank to an empty one.

The sand in the tank is supported on a canvas filter which is stretched over cocoa matting, which cocoa matting in turn is supported on a steel grating of about ¼ in. mesh. This steel grating in turn is carried on a steel grid resting on the tank bottom permitting free circulation of the solvent beneath the filter. The canvas has a life of seven to eight months and the cocoa mattings are changed with every second canvas.

After the tank is filled with sand the excess water is drained off, the tank is leveled by means of vertically directed water jets, the cover is put on, and the leaching solution is run upon the sand from the radial solution piping. The

* Eng. and Min. Journal, July 14, 1917. Trans. A. I. M. M. E., [illegible] Department of Commerce.

Figure 12. Shore plant classifying building, Lake Linden.

sewer valve is opened during this stage of the operation and the leach is run on as quickly as possible without overflowing, so that the water in the interstices of the sand is displaced downward by the on-flowing leach. When ammonia begins to show in the effluent solution the sewer valve is closed and the pregnant solutions are run into their proper effluent pipe line. The rate of flow of the leach is then reduced to the predetermined figure of about 34 cubic meters per hour for a total quantity of 650 cubic meters.

After the leaching solution has been led on to the sand, it is drained down for about an hour and 170 cubic meters of wash added. This wash is high in ammonia but low in copper. It has a slight leaching effect but its main object is to displace the rich copper-bearing leach. After the first wash there is another period of drainage and 50 cubic meters of strong ammonia distillate is used. The function of this distillate or second wash is to remove or wash out the copper which is still adsorbed in the sand. After this distillate wash some 70 cubic meters of water is run upon the tank, it is drained for about five hours and then steamed to remove the last traces of ammonia. The steam is applied above the sand through a special sewer, and suction applied from the bottom pulls the steam through the entire body of sand thus heating it up and carrying to a condenser the remaining ammonia.

While on-going solutions have been applied as above, the effluent solutions have been drained off as follows: The first 15 to 30 cubic meters is of varying composition owing to dilution and may contain a certain amount of calcium and magnesium carbonate in suspension derived from reaction with corresponding chlorides in the lake water. It is run back to the leach storage tanks and then, dependent upon the quality of the sand, a quantity of rich solution approximating 150 cubic meters in volume is drawn off for distillation. This volume must contain an amount of copper equal to the quantity extracted from the sand, and is a variable regulated by the quality of that sand. Following this, 650 cubic meters of leach is drawn off which regenerates that solution, and after this in turn the wash is drained off approximating over a series of tanks the volume added in the previous cycles.

This wash completes the cycle so far as the solution is concerned. The spent ore is now flushed out and the tank is ready for the next cycle. The complete operation requires about 82 hours.

Distillation

Coincident with the dissolving of the copper values from the sand, the rich solution is distilled to yield its copper oxide. This distillation takes place in stills (*Figures 8 and 9*) furnished by the Semet-Solvay Company and are the same in principle though not in detail of design as the ordinary ammonia still used in by-product coke plants. Appropriate means must be taken to recover the suspended copper oxide from the spent liquors which is accomplished by means of American and Sweetland filters. (*Figure 10.*) The ammonia and carbon dioxide gases are condensed and returned to the leaching cycle as ammonium carbonate.

The ammonia loss per ton of sand treated is just under ⅛ lb. NH_3. The distribution of the cost per ton of sand treated for the year 1930 is as follows:

General Expense	2.5c
Conveying and classification	2.5c
Leaching:	
Ammonia	5.1c
Steam	5.0c
Other	2.2c
Distillation:	
Steam	2.9c
Other	4.1c
Total	22.5c

Calumet conglomerate ore is one of the few ores mined in this country that requires both leaching and flotation for its most economical treatment. It is quite possible that if the leaching process had not been invented a satisfactory metallurgical recovery could be made by grinding the ore to a fineness sufficient to liberate values for recovery by flotation. This would require, however, power that has not been available in the past and would be at a figure in excess of present operating costs.

For the year 1930 complete milling costs of this ore including stamps or coarse crushing, fine grinding by means of Hardinge mills, leaching of the sands and flotation of the slimes are as follows:

Primary grinding (stamps)	19.6c
Gravity concentration (wash)	3.3c
Secondary grinding (pebble mills)	8.9c
Flotation	7.4c
Leaching	10.4c
Tailing disposal	1.9c
Superintendence, sampling, etc.	2.5c
Total	62.9c

Lake Linden Reclamation Plants

The Lake Linden plant has recently been described in I. C. 6357 Department of Commerce, to which the interested reader is referred for such details as may not be given in this shorter article.

The various units are located along the shores of Torch Lake at a slightly lower level than the concentrator itself, and the treatment of fine material by leaching and flotation is in common with that of the corresponding product from the mine. This plant has been operating for some 15 years and the sands available are more than half exhausted.

It was recognized at least 30 years ago that there were values in the tailings that could be recovered at some time in the future, and every step of advance in metallurgy made this possibility more certain. The introduction of fine grinding machines was sufficient to warrant a beginning of operations and work was begun in 1913 with only recovery by gravity anticipated. The leaching process fortunately was developed shortly thereafter, and this in turn was followed by the application of flotation to native copper so that instead of the original anticipated recovery of 35 to 40 percent from grinding alone, there has been realized an actual recovery of approximately 90 percent of the values contained in the tailings.

There are five main operations to this metallurgical process separately housed as follows:

1. Dredge for picking up material from the lake and conveying it through a pontoon line to a central point on shore.
2. Shore pumping plant and classifying house where the material is classified into coarse sand requiring further grinding and fine sand ready for leaching and flotation.
3. Regrinding plant where material is ground to minus 35 mesh and liberated values recovered.
4. Leaching plant as described above.
5. Flotation plant as described in a separate article in this same issue.

The dredge adopted was of the hydraulic type and was purchased from the Bucyrus Company of South Milwaukee. It is a steel hull dredge 56 ft. wide and 110 ft. long. The dredge pump (*Figure 11*) has a 20 in. diameter inlet and outlet, with impeller 55 in. in diameter and is driven by a 1,250 hp. motor. The suction mouth is equipped with nozzles which discharge water under 150 lbs. pressure and keep the sand in agitation in front of the suction ladder. This has proven entirely satisfactory for this class of material, being simpler than the rotary cutter of the ordinary type of suction dredge.

The suction ladder is 141 ft. long and permits of dredging to a depth of 110 ft. The dredge is not self-propelling but is operated by swinging lines fastened to anchors in the water and to dead-men along the shore. These lines are operated by electrically driven drum-winches, the electric wires being carried into the dredge on towers attached to the pontoons which float the discharge pipes.

The pontoon pipe discharges at a fixed point on the shore onto a stationary screen 16 ft. by 20 ft. in size with openings 1 in. in diameter. This is so located that the sand runs from the screen into a pond or reservoir controlled as to discharge by a revolving bridge which carries the suction pipe of the shore plant pump. (*Figure 12.*)

The dredge has a rated capacity of 10,000 cubic yards per day. No effort is made to synchronize the operations of the dredge with that of the shore plant. The dredge operation is necessarily intermittent and the dilution of the material pumped varies from minute to minute. The shore plant pump on the other hand with fixed length suction and discharge line operates under uniform conditions which is naturally essential to the operation of the treatment plants.

The shore plant is really a stationary dredge. It is built upon a concrete dock

Figure 13. No. 2 regrinding plant, Lake Linden.

Figure 14. Shore plant classifying building, Tamarack reclamation plant.

constructed by driving piles through the sand down into the original lake bottom and upon these piles putting a cap of concrete 3 ft. 6 in. thick. In the shore plant are a 12-in. Morris centrifugal pump for elevation of the sand, screens for removing rubbish, drag belts for classification into coarse and fine and with the necessary equipment for pumping fine sands into the leaching plant classification system and a belt conveyor for conveying the coarser sand to the top of the regrinding plant. (*Figure 15.*)

The next step in the operation is the regrinding of the coarser sands. The regrinding plant building was one of the first built after the successful development of the Hardinge mills and contains 64 of these mills 8 ft. in diameter by 18 in. cylindrical length. The large number of mills of this size are more spectacular than efficient, but it has not seemed advisable to replace the present equipment with larger and more economical units. This regrinding plant has a capacity of about 3,000 tons per 24 hours. Grinding is in open circuit and pebbles are used for the grinding medium. This is very economical in operating cost and tests with ball mills have shown an increase in cost too great to offset the advantages of increased capacity.

The total cost of operation of the reclamation plant for the year 1930 based on tonnage dredged follows. These costs include leaching and flotation, operations sufficiently described or noted in previous paragraphs.

	Cost per ton
General administration, mine and mill	8.1c
Dredge and pontoons	1.5c
Shore plant and belt conveyor	2.9c
Regrinding	17.6c
Leaching	16.3c
Flotation	1.5c
Miscellaneous	2.5c
Total	55.8c

These costs are somewhat higher than average because the plant was operated only five days per week until November 15, at which date it was shut down completely and is not operating at the time of this writing.

Tamarack Reclamation Plant

The plant as described above is the reclamation plant treating the conglomerate sands of the original Calumet & Hecla mine. It represents a development extending over a construction period of possibly five years. Its operation was so successful that treatment of the conglomerate sands of the Tamarack Mining Company was indicated and a plant was built which started operation in 1925. Instead of units separately housed as in Lake Linden, the Tamarack plant has its three treatment operations of regrinding, leaching and flotation practically under one roof. Instead of Hardinge mills 8 ft. in diameter by 18 in. cylindrical length, the 8 ft. mills are 72 in. in length and have about three times the capacity of the smaller mill with a better mechanical efficiency. The entire plant has a capacity approximately two-thirds that of the Lake Linden plant.

The dredge and shore plant of the Tamarack do not differ materially from that at the older plant—in fact the dredge now being used at Tamarack was the one originally purchased for Lake Linden. Correspondingly, pumps and drag classifiers (*Figure 14*) are similar in operation in both plants and the coarse material is likewise conveyed by means of a belt conveyor to the top of the regrinding plant. (*Figure 15.*) There are 18 of these 8-ft. mills and the coarse sand after grinding is treated on Wilfley tables. The table tailings are classified into coarse sand for leaching and fine sand for flotation.

The leaching plant (*Figure 16*) consists essentially of six tanks, 54 ft. in diameter by 12 ft. high, with the necessary storage facilities for solutions and circulating pumps for the conveying of the solutions. There is a single dis-

Figure 15. Regrinding plant, Tamarack reclamation plant.

Figure 16. Ammonia leaching tanks, Tamarack reclamation plant.

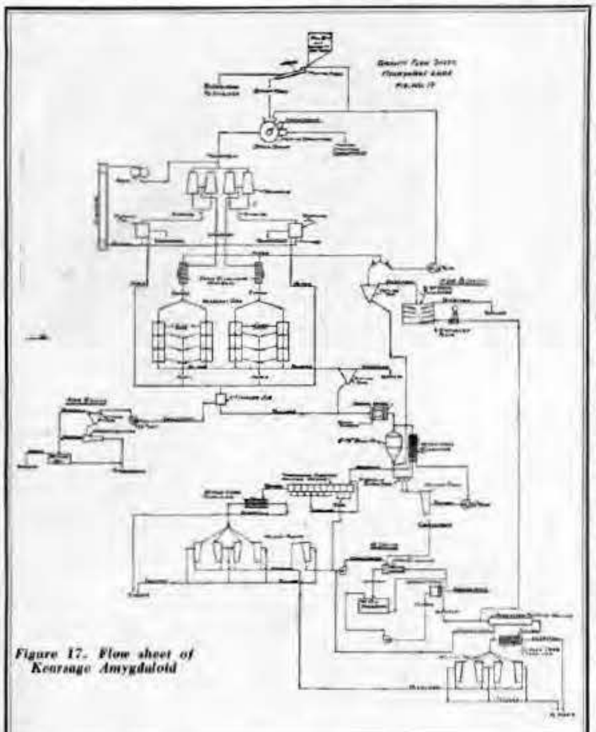

Figure 17. Flow sheet of Kearsage Amygdaloid

tillation unit in the leaching bay and one crane suffices for all purposes. The flotation equipment consists of four Dorr thickeners 40 ft. in diameter, four compartments each, and the thickened product is treated on a 16-cell minerals separation flotation machine.

The entire plant is very compact but costs are slightly higher than at Lake Linden owing to the lower capacity, and also to the fact that at Lake Linden a large part of the overhead is shared by the operation of treating the mine rock. The following figures will show the costs at the Tamarack plant for the year 1930. It was operating on reduced schedule to November 15, at which time all operations were suspended pending recovery in the demand for copper.

General administration, mine and mill	5.2c
Dredge and pontoons	8.3c
Shore plant and belt conveyor	3.9c
Grinding	11.6c
Leaching	16.3c
Flotation	2.2c
Miscellaneous	7.3c
Total	55.4c

Amygdaloid Practice

There have been no new mills built in the Lake Superior copper district for the treatment of amygdaloid ore in the last 20 years. There has been a decided change in the flow sheet in the last few years owing to the successful adaptation of flotation to relatively coarse material, but the stamps and coarse grinding stand very much as they did even 30 years ago. The great impetus to the development of the Lake Superior mines occurred in the copper boom of 1898 and amygdaloid crushing practice at least has been fairly well stabilized since about that time.

Owing to the very low copper tenor of the amygdaloid mines, all effort was for many years directed towards capacity of the stamping units and a low cost of metallurgical treatment. This was not done entirely at the sacrifice of metallurgical efficiency because fine grinding at that time was very much in its infancy and there were no practical means of saving liberated copper in the fine sizes. The capacity of the stamps was gradually increased by means of the introduction of ⅝-in. round openings in stamp mortar-screens followed by trommelling through a 3/16-in. screen. The oversize of the trommels was returned first in development to the stamps and later to high speed rolls. This is present practice and results in a capacity at the Ahmeek plant, about to be described, of over 800 tons per stamp unit per 24 hours. This is the maximum capacity unit on Lake Superior at the present time and is small compared to corresponding units in western practice.

The capacity of the mills is relatively small, the Ahmeek mill with its 6,500 tons daily capacity being the largest in the district. The small unit is not without its value so far as mining operations are concerned, because from the nature of the deposit there is no underground sampling done, and the mining captains get their best and only accurate knowledge of the quality of the ore from the stamp mill returns. With many of the shafts having a daily capacity only slightly in excess of that of a stamp unit, there is a correlation possible between these two operations, and it becomes necessary to keep the concentrates of the ore from the various shafts separate so that the mills partake something of the nature of custom units.

Where the shafts are on the same lode, in spite of the variation in copper content, the metallurgical process is uniform, but where the ore varies not only in quality but also in the nature of the distribution of the values, it becomes necessary to modify the metallurgy dependent upon the quality of the ore. So far this has been applied only to a variation in the extent of the fine grinding. In the case of the Osceola amygdaloid at the Ahmeek mill, a middling product is drawn off from the jigs to the extent of about 15 to 20 percent of total stamp capacity and this material is ground in ball mills to minus 28 mesh for flotation. In the case of the Kearsarge lode all of the coarse material (jig tailings) is ground to this size.

A flow sheet of the Kearsarge lode operation is shown in *Figure 17.*

Ahmeek Mill

The stamps at the Ahmeek mill are compound stamps of the Nordberg design (*Figure 18*). The high pressure cylinder is 16½ in. in diameter and the initial steam pressure is 150 lbs. The exhaust from this cylinder goes to a receiver and from this to the low pressure cylinder 32 in. in diameter, operating at a pressure of 38 lbs. These stamps are non-condensing and the exhaust steam at a pressure of 16 lbs. absolute goes to a low pressure turbine, thus giving a final mechanical economy that puts the efficiency of the combined unit well into the class of an electrically operated crushing device.

The stamp mortar discharges only at front and back, whereas most of the stamp mortars of the district are either four-way discharge or in some cases circular. The two-way discharge is ample to give sufficient screening capacity for the stamp product and is much more economical in upkeep. These stamp screens have 5/8 in. opening and the material goes first from these stamps to four trommels with 3/16 in. punched openings. The oversize of the trommels goes to a bull-jig which makes a 5/8 in. concentrate assaying well over 90 percent in copper. The tailings of the bull-jig go to a 36-in. by 16-in. high-speed Nordberg roll and thence to the original stamp trommels, the bull-jigs and rolls being in closed circuit with the stamp.

The material now finer than 3/16 in. in size is classified by means of two Dorr classifiers 3 ft. wide by 18 ft. 4

in. in length. The slimes from one of these Dorr classifiers (50 percent of total capacity) is returned to the stamp, replacing a corresponding volume of fresh water in order to save dilution. The slimes from the other classifier is settled out in a small settling tank, the plug product of which joins the ball-mill product for flotation, and the overflow of the tank is finally settled and thickened in a series of Dorr three-tray thickeners.

The Dorr classifier product is treated on Woodbury jigs for the removal of coarse concentrates and the entire tailings of these jigs ground in an 8 ft. by 72 in. ball mill. This ball mill has a capacity of from 450 to 550 tons per 24 hours, which capacity for coarse sand determines the original capacity of the stamp. Depending somewhat upon the nature of the ore approximately two-thirds of the original tonnage requires regrinding. The ball mill is in closed circuit with a heavy-duty duplex Dorr classifier 8 ft. by 25 ft. in size. The circulating load is about 300 percent and the crushing which varies somewhat with the load is held as nearly as possible all to pass the 28 mesh screen.

Closed circuit grinding has only recently been adopted in Lake Superior practice. Because of the nature of the ore, particularly the non-friability of the native copper, it was appreciated that it would be difficult to remove the liberated copper from the circuit. In early experiments along these lines, the copper built up until the value of the circulating load was many times that of the original feed and reached an equilibrium only when abrasion, which was very slow, balanced the liberated coarse copper. This made for very inefficient mechanical work and resulted in the production of large quantities of fine, almost floured copper, which was lost in the tailings of the tables treating the ground product. With the adoption of the flotation process for this product, the disadvantages of the abrasion was eliminated, but not the presence of a large quantity of liberated copper remaining in the circuit. It was necessary in some way to remove this material and in the flow sheet as adopted at the Ahmeek mill the product of the Hardinge mill is subjected to a hydraulic classification and the plug product from this classifier is treated on a Wilfley table, the tailings of which are returned to the ball mill. The closed circuit embraces not only the Dorr classifier but also the Wilfley table operating on a selected portion of the circulating load. This has proven very effective in removing the liberated values and has eliminated the last objection to closed-circuit work on ores containing native copper.

The crushing is at 70 percent solids. After crushing, with the plug product from the slime settling tank added, the dilution preliminary to classification is 60 percent solids. This material is then treated by flotation.

The flow sheet is really very simple. It consists essentially in grinding to minus 3/16 in. by stamps and rolls, classifying into sand and slimes, jigging the sand to separate out liberated copper, regrinding all jig tailings by means of the closed circuit ball-mill, and final flotation of the entire product of the unit.

The following grades of concentrates are made:

1. "Mill Mass," which consists of large pieces of extremely rich rock hand-picked before going to the stamps and which are sent direct to the smelter at about 60 percent copper.

2. The copper discharge of the mortar, consisting of nuggets ranging from 1 in. up to 3 or 4 in. and assaying 95 percent in copper.

3. Bull-jig concentrates, being material approximately 5/8 in. in size, and assaying from 92 to 95 percent in copper.

4. Woodbury jig discharge and hutch concentrates averaging 85 percent in copper.

5. Flotation concentrates averaging 60 percent in copper.

The first four classes of concentrates produced are sufficiently coarse so that they drain very rapidly and are ready for shipment to the smelter without any auxiliary treatment. There is a small quantity of copper produced on so-called finishing jigs or tables which is about 20 mesh in size and which is dewatered by means of a drag classifier before shipment. The flotation concentrates require special treatment and after a preliminary dewatering by means of a drag belt are filtered in a Dorrco filter, the water contained being reduced to 11 percent before shipment.

The costs of operation according to this new flow sheet are not sufficiently definite at this time to give in detail. A new power plant has just recently been installed, and lessened power costs will materially reduce final operating figures. Mine operations are also intermittent owing to the present unhealthy condition of the copper market, adding to the difficulty of obtaining representative figures. For the year 1930, operating without complete regrinding of jig tailings, the milling costs were 24.2c per ton.

The metallurgical extraction is well over 90 percent. For a given lode it varies directly with the quality of the ore. The Kearsarge lode has been yielding about 28 lbs. per ton and on ore of this quality, with fine grinding of all jig tailings, the final recovery is over 95 percent.

On Osceola ore there is not the incentive to high metallurgical recovery at added cost of treatment because of its low copper content. For a given grade, Osceola lode material will yield a higher percentage extraction than Kearsarge, because the distribution of the copper is in a coarser state. With ore assaying from 18 to 20 lbs. per ton, a jig tailing of 2 to 2½ lbs. per ton by assay can be obtained by drawing off only a relatively small percentage of the total sand as middling. At 10c per lb. copper, which is the selling price at the time this article is being written, the cost of recovering copper from jig tailings of this quality would just about equal the revenue to be obtained therefrom. It would probably require a market price of about 14c per lb. of copper to justify the necessary capital expenditure for grinding all Osceola lode sand to a size suitable for flotation.

As operated during the year 1930, the Ahmeek mill treated 1,193,704 tons of Kearsarge and 571,884 tons of Osceola ore and no effort was made to keep the costs separate on these two lodes. The table given below will show the most important data for this mill as a whole.

YEAR 1930

Ore stamped	[illegible] tons
Stamping rate per 24 hours	[illegible] tons
Tons ore stamped per lb. shoe worn	[illegible]
Tons ore stamped per ton steel consumed	28.16
Tons per man per day	25.45
Costs per ton stamped:	
General expense	.028
Stamps	.128
Grinding and gravity concentration	.063
Flotation	.021
Tailing disposal	.003
Total	.242

Figure 18. Steam stamps and auxiliaries, Ahmeek mill.

CALUMET AND HECLA CONSOLIDATED COPPER COMPANY

Figure 1. Boiler house at Lake Linden

Electric Power Generation

By
Robert McIntosh*
and
A. L. Burgan†

ELECTRIC power used by the Calumet & Hecla Consolidated Copper Company is generated by steam turbines at its mill and smelter plants. These are located along Torch Lake, which gives good condensing water facilities. The coal dock is adjacent, and a canal connecting to Portage Lake and through this to Lake Superior makes the dock accessible to all lake steamers. Thus excellent West Virginia coal is available at a low freight rate. These factors, together with economy resulting from the use of exhaust and process steam and waste heat, make for a low cost of power.

Power is generated at 25 cycles, 3 phase, with 13,600 volts on outside and interconnecting lines. There are eight turbines arranged to operate in parallel as one system. Their total generating capacity is 31,800 kw. at 80 percent power factor, or about 40,000 kva. They are located as follows:

At the LAKE LINDEN POWER PLANT

No. 1 turbine—8,000 kw. mixed pressure.
No. 2 turbine—9,000 kw. mixed pressure.
No. 3 turbine—2,000 kw. low pressure.

In the Still House at Lake Linden

No. 4 turbine—1,250 kw. back pressure.

At the SMELTING WORKS

No. 5 turbine—800 kw. on waste heat boilers.

At the AHMEEK MILL

No. 6 turbine—2,000 kw. low pressure.
No. 7 turbine—1,250 kw. back pressure.
No. 8 turbine—7,500 kw. high pressure.

The kw. ratings given are for 80 percent power factor and 40 degrees Centigrade temperature rise with the exception of turbines 4, 7 and 8, which are rated for 50 degrees rise.

At the Lake Linden boiler plant, built in 1905, there are 24 512-hp. Babcock and Wilcox boilers. (*Figure 1.*) Roney stokers are used with natural draft. Coal is delivered in railroad cars over a hopper leading to a link-belt double-roll crusher. It is crushed to 1 in. size and delivered to overhead coal bunkers by a Peck carrier. Each boiler is fed by a separate chute from the bunkers. The ash pits discharge to launders below them, pitched ¾ in. per foot, through which the ashes are flushed to a central sump. Coarse clinker is crushed through grate bars at the top of the sump box to prevent choking the cen-

Figure 2. Power plant at Lake Linden

* Mill Superintendent—Lake Linden Plants.
† Mill Superintendent—Ahmeek and Tamarack Plants.

Figure 3. Ahmeek Mill and Power Plant, looking east. Above the concrete are the steel ore bins served by a double track. Coal chutes under the rear track lead to coal bins built into the concrete supporting structure.

Figure 4. Ahmeek Mill Boiler House. Operating floor showing stokers, main steam piping and control panels.

Figure 5. Ahmeek Mill Boiler House. Forced draft fans with steam turbine drives.

trifugal pump which delivers the ashes to a sand-wheel to be disposed of with mill tailings.

Feed water is largely condensate from the surface condensers of the turbines and general heating system drains. Steam used for leaching and distillation in the ammonia leaching process is necessarily lost from the system so that considerable make-up is required. Raw Lake Superior water is used for this purpose. Cold feed water is circulated through ammonia condensing and cooling apparatus in the still house, accomplishing the necessary cooling without waste of mill water and substantially raising the feed water temperature. This is then brought up to about 200 degrees F. in open feed water heaters taking exhaust steam from the boiler feed pumps and steam stamps.

Each boiler is equipped with soot blowers which are operated at 8-hour intervals. After four or five weeks of service boilers are cut out for external washing and furnace repairs, and on alternate washings the tubes are turbined for scale removal.

Steam is generated at 180 lbs., at which pressure it is supplied through an 18-in. pipe to the turbines in the power plant and through an 8-in. pipe to the still house turbine. Steam for steam stamps, pumping, heating systems, and leaching, passes through a reducing valve set at 140 lbs., thence through a 24-in. pipe to the mills. Flow meters in each of these mains give the basis for steam charges to power, mill purposes and distillation. Each boiler is equipped with a Bailey meter, recording steam flow, air flow, and flue gas temperature, and indicating draft over the fire.

Figure 6. Ahmeek Mill Boiler House. Control compressors, ash pump and boiler feed pump.

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The power house, (*Figure 2*) separate from the boiler house, contains two Allis-Chalmers mixed-pressure turbines of equal size connected to generators of 8,000 and 9,000 kw. capacity, respectively, and one General Electric 2,000 kw. low-pressure turbine. The low-pressure turbine is connected to an independent 6-in. high-pressure steam line from the boilers for use should its power be needed when low-pressure steam is not available. Old reciprocating units which the turbines replaced have been removed, two of their generators being retained for use as synchronous condensers.

TABLE 1

	Kwh.	Percent of total
Lake Linden plant from high-pressure steam	101,653,000	76.0
Lake Linden plant from stamp exhaust	10,750,000	8.1
Lake Linden still house from process steam	2,763,500	2.1
Smelting Works waste heat	5,686,800	4.3
Ahmeek mill stamp exhaust	12,746,200	9.5
Total	132,999,500	100.0

The two mixed-pressure turbines each have a h'gh- and a low-pressure cylinder,

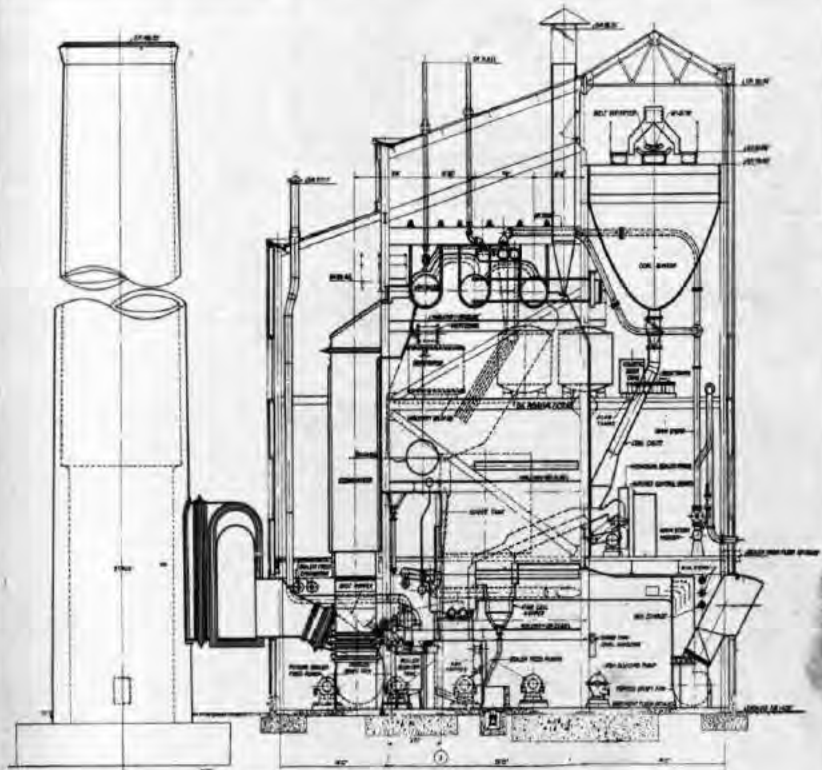

Figure 7. Ahmeek Mill Boiler House. Cross section.

Figure 8. Ahmeek Mill Power House. No. 8 steam turbine generator unit with its 13,600-volt switchboard.

Figure 9. Ahmeek Mill Power House. No. 8 turbine room, showing reinforced concrete turbine foundation and condenser.

the high-pressure cylinders operating on boiler pressure of 180 lbs. and exhausting to receivers connected to the low-pressure cylinders. Exhaust from the steam stamps also comes to the low-pressure cylinders through a 36-in. pipe from the mill. Pressure in this line is maintained at about 1 lb. above atmosphere by flow regulating valves at the turbines, to insure against leakage of air into the system. This 36-in. pipe acts as a low-pressure steam reservoir into which comes exhaust steam from the stamps, high-pressure turbine cylinders, feed pumps, and if required, part of the exhaust from the still house turbine. From it steam is taken for the low-pressure cylinders of the turbines, feed water heating and the heating systems of the main mill buildings. When stamps are not operating, low-pressure steam for heating is still available from the mixed-pressure turbines which then act as bleeder turbines.

Circulating water is taken from the mill pumping system. The pump house is located at the shore of Torch Lake about 800 ft. distant from the power plant with the mills between them. The pumps in regular use there are a 30-in. Alberger centrifugal pump, motor driven, with a capacity of 40 million gallons per day, and the pump Michigan which is a triple expansion reciprocating steam pump of 60 million gallons per day capacity. Both operate against a total head of 60 ft. and either can supply water for condensing or mill purposes. Condensing water used in the power plant is returned for mill use by a 30-in. motor driven centrifugal pump.

Located in the still house is a 1,250 kw. DeLaval geared turbine unit receiving steam at 180 lbs. and exhausting at 18 lbs. above atmosphere, as required for use in distillation of copper-ammonia solution from the leaching plant. Its purpose is to utilize for the production of power the necessary drop in pressure. The amount of power produced depends upon the demand for steam by the stills and is controlled by a pressure governor on the exhaust side of the turbine. Speed is fixed by synchronous operation with the main power system. Operation of the stills on this exhaust steam has been quite satisfactory and is better than when the necessary pressure reduction takes place by throttling. Steam used by the stills does not fully load the turbine and provision is made to bring it up to capacity by passing more steam than the stills require and returning the excess exhaust to the low-pressure steam system to be used in the low-pressure cylinders of the turbines in the power plant.

At the Smelting Works a Westinghouse 800 kw. turbine operating at 150 lbs. pressure, condensing, is supplied with steam from waste heat boilers. Two melting furnaces discharge their hot gases through 800 and 396 hp. boilers respectively and two refining furnaces each have a 396 hp. boiler. Steam is thus available for power and heating purposes most of the time and two of the boilers can be fired independently if required. This is not ordinarily done for power generation because at times when steam from waste heat is not available power can be taken from the general system at less cost.

At the Ahmeek mill exhaust steam from the stamps goes to a 2,000 kw. low-pressure turbine, which may also be operated by high-pressure steam under governor control.

The 1929 records show the gross output of the system 132,999,500 kwh. That year is representative of recent operation without the new units at the Ahmeek mill which have been operating but a short time and under unfavorable load conditions. Power supplied by the various units was as shown in Table I.

The first item, 76 percent, represents output by fuel burned primarily for power generation. The other four items amounting to 24 percent of the total show the amount of power developed as a by-product of the milling and smelting operations. The units supplying by-product power necessarily operate to suit the work of the plants at which they are located. The Smelting Works and Still House turbines are not depended on to follow power demand, but they effect a substantial saving in coal, amounting to about 6,000 tons in 1929. The output of the turbines from stamp exhaust follows demand closely since it is about equal to the amount of power used for mill operation, and is always supplied when the mills work.

Steam stamp economy is not more than 10 or 15 percent better with condensing than with non-condensing operation. Experience at the Ahmeek mill showed an increase in steam consumption for the entire plant of 8,000 lbs. per hour when the change was made from operating stamps condensing, to operating them non-condensing and generating electricity with their exhaust steam. The exhaust steam turbine generated 2,000 kw. with an increase in steam consumption for the whole system of only 8,000 lbs. per hour, equilavent to 4 lbs. steam per kwh. produced.

New Power Plant—Ahmeek Mill

The Ahmeek Mill power plant, at this writing in operation only four weeks, was designed to generate 8,750 kw. and in addition, to supply 80,000 lbs. of steam per hour to the mill at 160 lbs. pressure to take the place of a boiler house in need of replacement.

The scheme adopted after careful consideration and in consultation with Stone & Webster Engineering Corporation, was to make steam at 425 lbs. pressure and 200 deg. superheat, to generate 7,500 kw. with boiler pressure steam direct to a condensing steam turbine unit, and 1,250 kw. from a high-pressure turbine generating unit acting as a reducing valve, and supplying steam at 160 lbs. pressure for the mill.

Freedom from interruption of service being of paramount importance, the boilers were installed of such size that although all three boilers are normally in use, two can carry the load.

Auxiliaries common to all three boilers are in the west end of the boiler house, and large enough to serve a fourth boiler. The east end of the building is constructed to provide possible extension for a fourth boiler should the future make such an addition desirable.

Buildings

Both the boiler house and the 7,500 kw. turbine room are of steel frame covered with galvanized corrugated iron over 2 in. matched wood sheathing with paper between. Steel sash with hinged windows and roof ventilators furnish light and ventilation. The roofs are of

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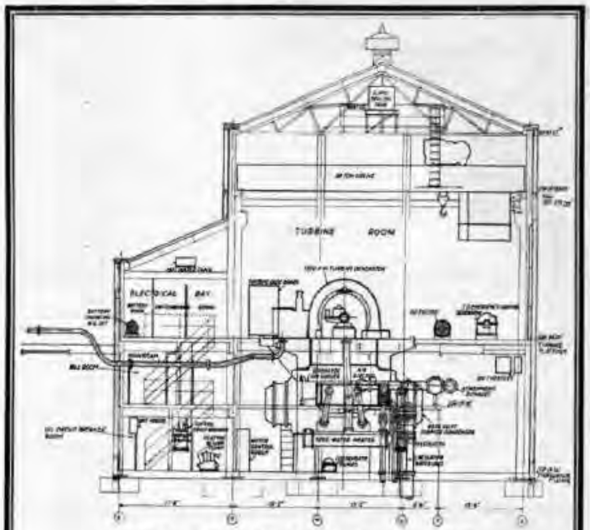

Figure 10. Ahmeek Mill Power Plant. Cross section, mechanical equipment.

precast gypsum supported on steel framing and covered with 4-ply composition roofing. The inside walls are finished with cement plaster on metal lath. Concrete piling supports all columns of buildings and conveyor as well as the foundations for turbines, boilers, and stack.

The turbine building is equipped with a traveling crane designed for a 30 ton normal load, and 47½ ton occasional load. The necessary heat in this building is provided by unit heaters, the condensate being returned by pumping to the turbine condensate pipe line.

Figure 3 gives the general layout of buildings and their relation to the mill.

Coal Handling

Existing coal bins which served the old boiler plant are utilized. They are incorporated in the concrete structure which supports the mill rock bins about 55 ft. above the ground. Coal is delivered in 22-ton cars over the company railroad and dumped from the rock service track through hoppers and chutes into the bins.

From the bins coal runs by gravity to a 24-in. apron conveyor traveling east 12 ft. per minute, which conveyor delivers the coal to a 26-in. by 24-in belt driven 2-roll crusher. The crusher drops the coal in sizes 1½ in. and smaller to a troughing belt conveyor traveling south. This belt is 170 ft. between centers, is 20 in. wide and inclined at an angle of 18 degrees. It in turn delivers the coal to another similar conveyor, 213 ft. centers, traveling west over the suspended bunkers in the boiler house and distributes the coal by means of a tank type tripper.

Boilers

The boiler house equipment is designed to furnish at normal load 180,000 lbs. of steam per hour at 425 lbs. pressure, 200 degrees superheat, corresponding to a temperature of 675 degrees. Deducting the steam used by auxiliaries, about one-half is for mill purposes and the other half for power generation.

There are three 8,955 sq. ft. Stirling, 4-drum boilers built for 450 lbs. pressure. Each is provided with superheater, soot blowers, 5,800 sq. ft. economizer and stoker. The stokers are the single ended 7-retort, 38-tuyere underfeed type with double roll clinker grinder and coal hopper agitator. The stokers are driven by individual steam turbines using boiler pressure steam and exhausting at about 5 lbs. pressure. They are equipped with hand and automatic speed regulators.

Each boiler has a turbine driven forced draft fan and a motor driven exhaust fan. This latter may be operated at either of two speeds, being coupled to two motors, one at either end, with speeds 710 and 460 r. p. m., respectively. The forced draft fan has a capacity of

Figure 11. Ahmeek Mill Pump and Turbine Room. In the foreground is the 28,000-g. p. m. triple expansion reciprocating pump. On the same floor is the No. 7, 1,250-kw. reducing turbine unit and the by-pass reducing valves. In the rear is the No. 6 2,000-kw. exhaust steam turbine unit and the 2,300-volt switchboard.

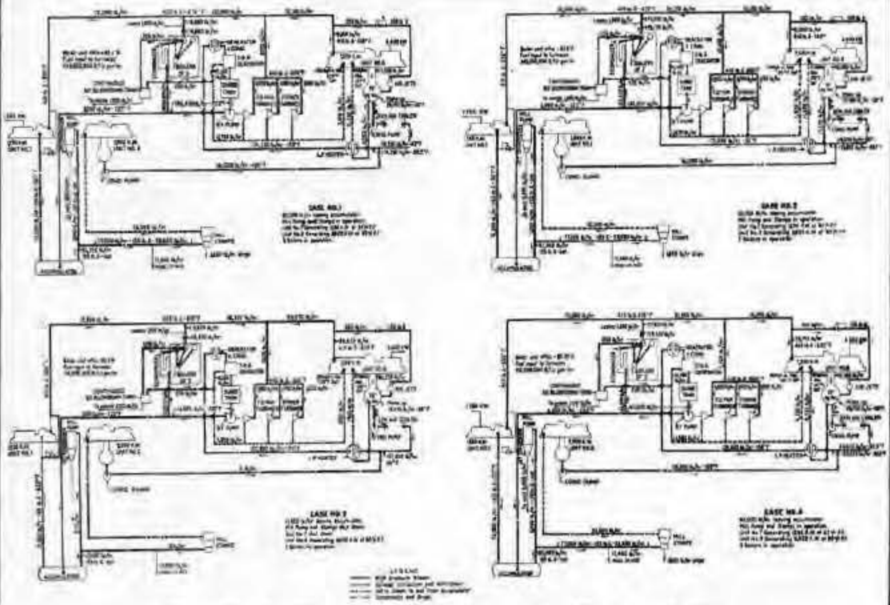

Figure 12. Heat Balance Diagram. Piping system, Power Plant, Ahmeek Mill.

40,000 c. f. m. against a static pressure of 9 in. of water. The exhaust fan capacity against the same head is 70,000 c. f. m. at 710 r. p. m. and 35,000 c. f. m. at 460 r. p. m. The exhaust fans deliver to the stack which is of reinforced concrete 12 ft. inside diameter and 175 ft. high.

Three 450 g. p. m. four-stage centrifugal boiler feed pumps direct connected to steam turbines and with duplicate water lines to economizers are provided, one pump having sufficient capacity to serve all three boilers at normal load of 180,000 lbs. of steam per hour.

Figure 4 gives a view of the main steam piping, stokers and control panels. *Figures 5* and *6* show the forced draft fans and feed pumps. *Figure 7* is a cross-section of the boiler house which gives the general layout.

Combustion Control

By means of combustion control equipment the boiler uptake draft and the quantities of air and fuel supplied to the furnace are adjusted to suit the load on the boilers. As the load varies, the pressure in the main steam header changes, slightly, actuating a master controller which changes the settings of the three induced draft controllers, one for each boiler. These in turn adjust the uptake draft dampers and the settings of the stoker turbine speed governors. Furnace pressure controllers actuated by the master controllers operate to hold constant furnace pressure by adjusting the forced draft dampers. This maintains main header pressure within 5 lbs. above or below normal. Compensating relays permit of adjusting the relative load on the different boilers at the will of the operator or of holding any boiler at a fixed load while the other boilers take the load changes.

Ash Handling

Airtight ash hoppers 12 ft. by 5 ft. by 8 ft. deep are built directly under the clinker grinders and reach to the boiler house floor which is at surface grade. Hand-operated water nozzles direct streams of water which sluice the ash through doors at the floor level into the hydraulic system. The hydraulic system consists of 560 ft. of 8-in. hard white cast-iron pipe and fittings laid under the boiler house floor in front of the ash hoppers, and continued in a concrete trough just below surface grade to the mill slime tailings pump. The sluicing nozzles located at proper points along the line of 8-in. pipe are supplied by a 600 g. p. m. motor driven pump, at 160 lbs. pressure. Fifteen tons of ash per hour can be handled.

7,500 Kw. Turbine

The 7,500-kw. unit operates at 1,500 r. p. m. and takes steam at 425 lbs. pressure and 650 degrees temperature. Three extraction nozzles are provided for heating the condensate and make-up water for boiler feed.

Condensing equipment consists of an Ingersoll Rand suspended two-pass, single compartment surface condenser, with 2-stage steam-jet air ejector. A horizontal double suction motor driven pump located in the mill pump house furnishes 11,000 g. p. m. circulating water required by the condenser. The 30,000 g. p. m. required by the Ahmeek mill is pumped from a well which is fed at its south end by gravity from Torch Lake. The 11,000 g. p. m. circulating pump takes its water from the south or inlet end of this well and when the mill pumps are running, which is 80 percent of the time, the circulating water discharge from the condenser returns to the north end of the well below water, to eliminate static head on the pump. The excess water required by the mill pumps over the amount taken by the circulating pump assures condensing water of lake temperature. When the mill pumps are not operating, the circulating water from the condenser is by-passed to Torch Lake.

Figures 8 and *9* show the turbine with its auxiliaries and switchboard, and *Figure 10* is a cross-section of the plant showing the general arrangement of turbines, auxiliaries and switchboard.

1,250 Kw. Turbo-Generator-Reducing Valves-De-Superheater

The Ahmeek mill requires 80,000 lbs. per hour of dry saturated steam. A 1,250-kw., back-pressure unit is used to reduce the boiler pressure of 425 lbs. to

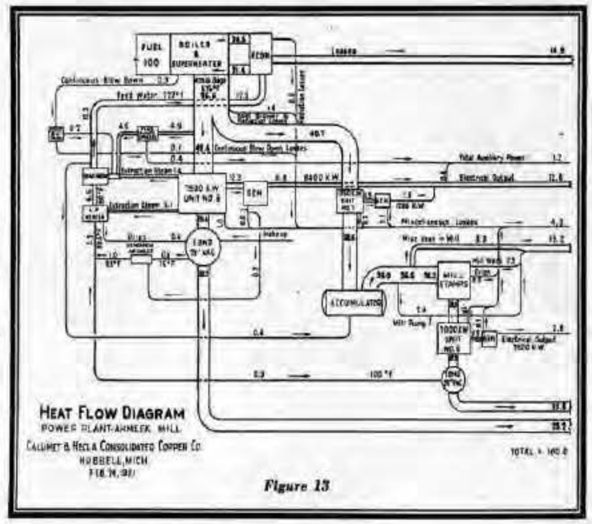

Figure 13

165 lbs. The turbine running at 4,500 r. p. m. operates the generator at 750 r. p. m. through reduction gears.

The exhaust steam from this turbine carries about 140 degrees of superheat. When the mill is shut down or if for any other reason the 1,250-kw. turbine is not running, the necessary steam for the mill is by-passed. Three by-passes are provided; one 4-in. with hand control, and one 4-in. and one 2-in. with regulators set to hold a constant pressure slightly under the back pressure of the turbine. When all the mill steam is taken through the by-passes, its superheat is 250 degrees as compared with 140 degrees in the turbine exhaust.

As the mill machinery is not adapted to the use of superheated steam, it is necessary to use a de-superheater to give dry saturated steam for mill purposes. This is of the accumulator type, 8 ft. in diameter by 30 ft. long. It requires for de-superheating approximately 6,500 lbs. of water per hour when the turbine furnishes the steam and about 12,000 lbs. per hour when steam is taken through the by-pass system. About 3,000 lbs. per hour of the de-superheating water returns by gravity to the accumulator as condensates from steam stamp re-heaters and main steam lines.

Figure 11 shows the turbine together with the by-pass equipment. It also shows the exhaust steam turbine and 2,300-volt switchboard as well as the Nordberg 28,000 g. p. m. mill pump.

Feed Water

Under normal conditions the boiler feed water is made up of approximately 50 percent condensate from the 7,500-kw. unit, 35 percent from the 2,000-kw. exhaust steam unit, and 15 percent Lake Superior make-up water.

Water is pumped from Lake Superior for boiler feed and domestic purposes. To protect against lengthy interruption of this service, occasionally of 24 hours duration, a reservoir is provided at a convenient elevation a few hundred feet from the boiler house. It has a capacity of 350,000 gallons, sufficient to take care of make-up for 96 hours. A float valve on the inlet keeps the reservoir full.

The make-up water enters the condenser of the 7,500 kw. turbine and is pumped with the condensate through the generator air cooler, adding a few degrees to the water temperature. The condensate from the condenser of the 2,000 kw. turbine then joins the water coming from the air cooler and passes through a closed heater supplied with steam at 2 to 3 lbs. absolute from an extraction nozzle on the 7,500 kw. turbine. This feed water now at a temperature of 125 deg. F. passes through a deaërator vent condenser and a vertical cylindrical deaërating heater in the boiler house. The steam for the deaërating heater consists of the exhaust from the turbines driving the boiler feed pumps, forced draft fans, and stokers, supplemented by additional steam at 3 to 6 lbs. gauge pressure from an extraction nozzle on the 7,500 kw. turbine. The water leaving this equipment at 220 deg. flows to a surge tank and then to the boiler feed pumps from which it passes through the economizers, entering the boilers at a temperature of 330 deg.

A 10,000-gal. surge tank is provided with an upper float valve which controls the flow of make-up water entering the condenser of the 7,500 kw. unit by admitting just the amount necessary to maintain the surge tank water level below the overflow point. A second float valve about 4 ft. lower than the first provides for the control of make-up water direct to the deaërating heater when the 7,500 kw. turbine is idle, or if for any other reason that source of feed water fails. In this case the condensate from the 2,000 kw. turbine also is passed to the deaërating heater instead of entering the feed water system ahead of the closed heater in the turbine room.

Feed Water Treatment

The steam for the 2,000 kw. turbine being the exhaust from the stamps, the condensate from this turbine contains lubricating oil. This condensate represents 35 percent of the total feed water. Two pressure type sand filters with coagulent and alkali feeding equipment are used to remove this oil before it joins the rest of the boiler feed water.

To provide for the desired limitation of the boiler water concentration, a continuous blow-down pipe leading to a flash tank is placed in the middle upper drum of each boiler. The major part of the heat in the water so blown down is reclaimed by the steam flashing to the deaërating heater.

The Hall Laboratories system is used to control the chemical composition of the boiler water and to prevent the precipitation of dissolved solids in a form which would cause adherent scale on the boiler surfaces. Phosphate, which is fed direct to the boilers, by combining with the scale-forming elements in the feed water, forms finely divided insoluble phosphates which remain in suspension and are removed by blow-down. As this phosphate reduces alkalinity, caustic soda is added to maintain the proper basic condition of the boiler water to protect against corrosion, foaming, and caustic embrittlement. Sodium sulphate, which is fed into the surge tank, tends toward the same result. These measures, together with the deaërating heater, assure protection against impure water.

Instruments

Recording and indicating meters are used to furnish information for efficient operation of boilers and turbines as well as to determine the proper distribution of steam and power costs.

Counters on the stoker retort driveshafts, when calibrated in service over a period of months, will permit of determining coal consumption rate for any boiler. This, together with steam flow integrating meters for each boiler as well as for total plant load, makes it possible to follow daily the plant or individual boiler efficiency.

Figure 12 gives the heat balance with four different sets of conditions as to mill and electrical load, and *Figure 13* is the heat flow diagram under full load.

Power Costs

Without interest and depreciation charges, exhaust steam turbine costs are under .20 cents per kwh. It is too early to give the power costs of the new turbines, but it is expected that these will be under .20 cents per kwh. for the 1,250 kw. unit, and under .33 cents per kwh. for the 7,500 kw. unit.

Stone & Webster Engineering Corporation started field work on this plant July 1, 1930, and seven months later, on February 1 of this year, the plant was in full service.

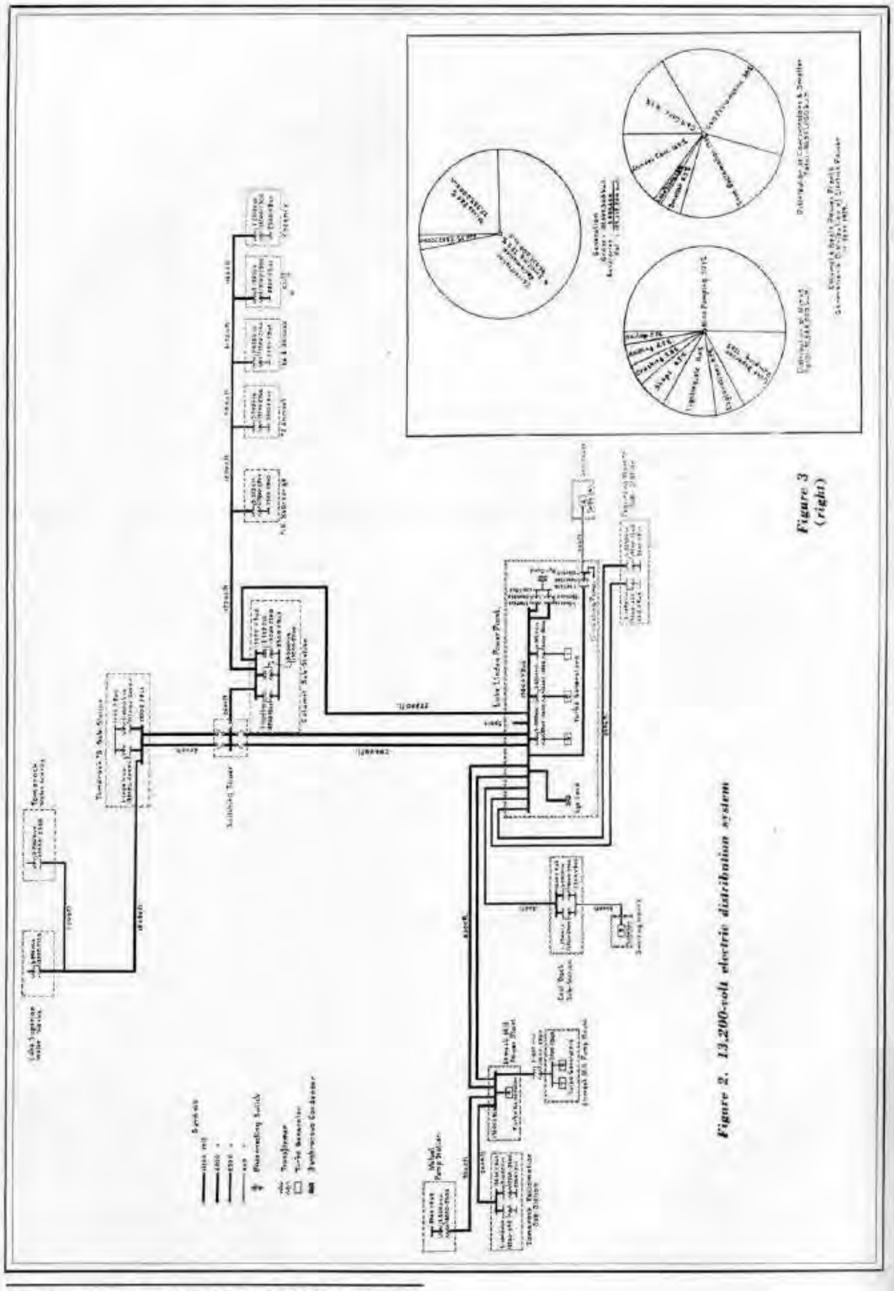

Figure 2. 13,200-volt electric distribution system

Figure 3 (right)

Transportation System and Coal Dock

Figure 1. First Calumet Mill, 1867.

Figure 2. Old incline to Calumet Mill on Torch Lake, 1867 to 1886.

By Frank H. Haller*

WHEN the copper mines in the Keweenaw Peninsula of northern Michigan were opened in the 60's or earlier the nearest railroad was at Green Bay, Wis., 220 miles away and any mining company requiring transportation facilities was compelled to create them. Fortunately, however, most of the mines were within a few miles of harbors on Lake Superior or its inlets, such as Portage Lake and Torch Lake, which permitted shipments of machinery and supplies to be made in the summer by boat, from manufacturing centers on the lower lakes. These were delivered to the mines after comparatively short hauls over wagon-roads or tram-ways; but during the season of closed navigation on the lakes, absolute necessities had to be teamed all the way from rail transportation terminals. Shipments of copper from the mines were made in the same fashion, by boat or by long overland hauls. All-rail traffic into and out of the copper district of Michigan was not possible until the Marquette, Houghton & Ontonagon railroad was completed in the fall of 1883, more than 17 years after the Calumet mine was opened. In the meantime the custom of shipping everything possible by lake vessels became firmly established and, until a few years ago, the greater part of the copper shipped from Michigan refineries went out by boat. Today the docks on both Portage Lake and Torch Lake are readily accessible to the largest of the Great Lakes carriers and all shipments of coal as well as other bulk and package freight are received by boat. (See maps.)

The first stamp mill for the Calumet mine was only a short distance away and the ore was hauled to it in horse-drawn tram-cars. (See *Figure 1.*) The first mill for the Hecla mine was located on Torch Lake and the "Hecla and Torch Lake" railroad was built in 1867 to connect it with the mine. This railroad was four and three-quarters miles long ending at the head of an incline of variable pitch, a mile long, the lower end reaching to the ore-bins of the mill. The grades of the incline were much too steep for the locomotives that operated on the railroad; but the loaded cars going down drew the empties up by means of wire rope connections—a method then commonly used at several properties in the district. (See *Figure 2.*) Incoming supply shipments by lake vessels were unloaded at a dock on Torch Lake and hauled to the mines over this railroad. The gauge of the track was 4 ft. 1 in., the cars were four-wheeled boxes carrying 2½ tons of ore, and the locomotives were very small. After some years the Hecla mill was enlarged, a new Calumet mill was built close to it, mine production was increased, cars carrying double the tonnage were built and larger locomotives were purchased; but the old incline continued in commission for 19 years. About 1885 a better

* Superintendent of railroads.

Figure 3. American Consolidated type locomotive and train of loaded 40-ton ore cars.

Figure 5. Clearing railroad tracks in a climate where the normal snowfall is 8 or 9 feet each winter.

location for the lower end of the railroad was determined upon; the new route added somewhat to its length but greatly reduced its grade and made possible the use of locomotives all the way. The incline was finally abandoned in 1886. By 1906 the company's plant at Calumet and its mills and smelter on Torch Lake had very greatly expanded; extensions and sidings of the railroad had been built at a rapid pace to keep up with the increasing business, but the small cars were a tremendous handicap; finally it became fully evident that larger cars of an up-to-date design, using air-brakes and standard couplers, were absolutely essential. An order for 140-ton ore cars of steel and wood construction was given to the American Car and Foundry Company; these were specially designed to negotiate the sharp curves established years before in and around the buildings. All tracks were changed to standard gauge, 4 ft. 8½ in.; a dozen or more locomotives were broad-gauged as well as all the flat cars, mineral cars, etc., in use at that time. This work was accomplished without interfering with production from the mines.

Since then the Calumet and Hecla railroad (still spoken of as the Hecla and Torch Lake) has continued to grow both in equipment and in tonnage handled but has remained a private industrial system. Its main line is five miles long from the mines to the mill yards and is laid with 90-lb. and 80-lb. steel. At the Calumet end it has extensions, branches and sidings totaling 22 miles of track laid with 80-lb., 70-lb. and 60-lb. steel. At the lake end it serves the various mill buildings, the smelter and the coal dock with 10½ miles of branches and sidings. The rolling stock consists of 250 hopper-bottom ore cars of 80,000-lb. capacity; 19 all-steel, 100,000-lb., bottom-dump mineral cars; 35 steel, 8-ton mineral cars; 90 wooden, 12-ton, side-dump, waste-rock and ash cars; 35 wooden flats and gondolas; 6 steel, 12-yd., Western air-dumpers; 6 wooden, 30-ton box cars, and three passenger coaches for occasional service in carrying employes to and from work.

In 1923 the Ahmeek, Kearsarge, Allouez, Centennial and Osceola mines were merged with Calumet and Hecla and, being without railroads of their own, shipped their ore by the Mineral Range railroad from mines to mills over an indirect route with heavy adverse grades. The tariff rates were so high on this line that, during and after the working out of the consolidation, much serious thought was given to planning a more direct route with moderate grades, to be built and operated by the Calumet and Hecla Consolidated Copper Company and in 1925 this railroad was completed; It is 9½ miles long from the Ahmeek mine to the mills at Torch Lake. Several miles of branch track, 100 steel, 50-ton ore cars, 2 consolidation-type locomotives weighing 206,000 lbs. each (See *Figure 3*), and other auxiliary equipment were purchased from the Mineral Range railroad for the new line, the whole being spoken of locally as the Trap Rock Valley railroad. In addition to the new track, laid with 80-lb. steel,

Figure 6. No. 2 Russell snow plow with wing elevators and flanger.

COPPER, ORE, COAL, MINERAL, ETC., HANDLED

Year	Copper ore to mills	Coal from dock to mines & mills	Mineral to smelt.	Waste rock to dump	Sundry commodities moved	Total tonnage handled
1926	2,365,933	426,696	98,097	58,266	137,000	3,084,792
1927	2,754,358	436,399	94,911	104,197	127,425	3,517,290
1928	3,073,382	436,964	104,218	137,021	190,175	3,941,760
1929	3,150,110	445,876	104,475	137,859	177,025	4,015,145
1930	2,951,475	401,879	87,048	151,821	149,250	3,742,073
Total	14,293,258	2,147,814	490,149	588,964	780,875	18,301,060

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there are now 11¾ miles of extensions and sidings laid with 80-lb. and 70-lb. steel at the mines and mills. This line connects with the Hecla and Torch Lake railroad and both are operated as one system.

In spite of the rugged, hilly country traversed by the new railroad, a maximum allowable grade of 6/10ths percent and a maximum curvature of 8 degrees was adhered to in construction. The average grade is 35/100ths percent and favors the loads at all points. Aside from two concrete and steel viaducts over an interurban car line and a state highway, there are no bridges on the line except the steel trestle approach to the Ahmeek mill. (See *Figure 4.*) There are, however, many galvanized, corrugated metal and reinforced concrete culverts and many heavy fills. Necessary earth and rock cuts averaged 36,810 yds. per mile; fills average 63,035 yds. per mile, the extra material in most cases being obtained by widening the cuts.

Conditions in the copper industry have been such that traffic handled on the Trap Rock Valley line has never approached the tonnage counted upon when it was planned. Nevertheless, the unit cost of transportation has been below the expected figure, and during the five years of operation (up to the fall of 1930), the savings to the company on actual tonnage hauled have been well over a million dollars, which more than repays the entire cost of construction and equipment.

As stated above, the old railroad and the new are operated by the mining company as one system with 14½ miles of main line and over 44 miles of branches, extensions and sidings. To keep these tracks cleared for action at all times in a climate where the normal snowfall is 8 to 9 ft. each winter is not a small task. (See *Figure 5.*) Permanently erected snow-fences are necessary in many places, including the yards around the mines, and substantial snow-plowing equipment is required. A No. 2 Russell plow with wing elevators and flanges is used for single-track lines, while six smaller plows of various types, with adjustable wing-spread, are kept for clearing yards where two or more tracks lie parallel. (See *Figure 6.*) Three locomotive cranes (a Brownhoist and two Industrials) with extra large clam-shell buckets are also used for moving snow banks. (See *Figure 7.*)

All copper ore, mineral, coal, etc., handled in the mining company's operations is weighed on standard railroad track scales. At the approaches to the stamp mills there are three 75-ton Fairbanks scales with Streeter-Amet automatic tape recording attachments; at the coal dock and the smelter there are three installations with Howe patent recording beams.

The round-house at Calumet is a stone and steel structure having stalls for 15 locomotives and repair pits for two more in a shop adjoining. At convenient points around the mine and mill plants there are three locomotive coaling stations and six water supply stations. (See *Figure 8.*) The dispatching of trains is accomplished by telephones connecting eight make-up yards, terminals and junction points. A well equipped car-repair shop is maintained at Calumet adjacent to the mine shops and foundry.

The amount of copper ore, coal, mineral, etc., handled during the past five years is shown in the table on page 516 in tons of 2,000 lbs.

Above—Figure 4. Steel trestle approach to the Ahmeek Mill.

Left—Figure 7. Locomotive crane with extra large clam shell for loading snow or ashes.

Figure 8. Coaling station and water tank, and two Trap Rock Valley locomotives at Ahmeek.

COAL DOCK

An old type of apparatus used for unloading coal from boats about 45 years ago is shown by *Figure 9.* Like others, it served its intended purpose for a period and then made way for something better.

The coal-handling bridge now in use was furnished and erected by the Mead-Morrison Manufacturing Company and went into commission in the summer of 1918. The bridge is equipped with a man-trolley operating a 9-ton automatic grab-bucket and two loading-out hoppers mounted in the supporting towers or "pier-legs." The man-trolley carries the traveling and hoisting motors, the drums and brake mechanism and the operator's cab, which is suspended in a convenient

Figure 9. Old coal dock in use 40 or 50 years ago on Torch Lake.

Figure 10. The coal bridge and dock from the lake. The boat in the foreground is the "Hansa" discharging a cargo of Belgian pebbles.

position for clear observation. The entire bridge travels at the rate of 60 ft. per minute lengthwise of the dock on four 100-lb. steel rails. The total weight is supported on 32 30-in. diameter wheels similar in pattern to standard car wheels. (See *Figures 10* and *11.*)

The main bridge span is 382 ft. 6 in. in length, the cantilever overhanging the rear leg being 116 ft. long and the extension toward the lake 37 ft. in length ending vertically above the face of the dock at which point the "apron-end" is pivoted. This overhangs the water 75 ft. beyond the face of the dock, permitting the trolley to run out to points vertically over boat holds and may be swung up to a vertical position over the dock face so as to offer no obstruction to ship masts, etc., when vessels are being shifted along the dock. The bottom chord of the main truss is 70 ft. vertically above the dock level and the clear space below the bucket allows 47 ft. for storage.

The scheme of operation is both simple and economical. A coal boat with a cargo of 8,000 or 10,000 tons ties up alongside the dock, the apron is lowered over the boat, the bridge is moved to the right position over a hatch, and unloading gets underway quickly at the rate of 300 to 600 tons per hour depending on the discharge point of the grab-bucket. The longitudinal storage space under the main span is about 1,400 ft. long, having capacity for 475,000 tons with additional space available under the cantilever for about 60,000 tons. When delivering freely from the hold of a ship to the hopper in the front pier-leg, with sufficient railroad cars available for loading, the capacity of the equipment is over 600 tons per hour. Ordinarily, however, during the 20 or 24 hours required to completely unload a boat, only 1,000 or 1,200 tons is put into cars, all the rest being dropped on the pile. In the intervals between the arrival of cargoes or in winter, the coal in storage is reclaimed by the same 9-ton bucket that is used in unloading boats. There are two railroad tracks along the dock front for loading cars from the front hopper and another track at the rear, as shown in the larger picture, *Figure 11.*

It is not customary to use all the stock-pile space for steam coal. At the north end there is a bin of 4,000-tons capacity for storing Danish pebbles which are used in the milling operations. *Figure 10* shows the bridge unloading a cargo of pebbles. At the south end of the dock considerable space is taken by piles of anthracite, crushed limestone and coke screenings, so that the room available for storing steam coal has a capacity of approximately 400,000 tons.

Both automatic and manually operated rail-clamps lock the bridge structure to the abutments except during the few moments required to move from hatch to hatch or from one part of the pile to another. Safety devices are installed, however, to prevent any movement at all when the wind velocity is excessive. A recording anemometer placed on the top chord of the bridge is arranged to operate visible warning signals and to break the traversing power circuit when the wind is excessive; in fact, if the bridge is traveling safely and a strong gust of wind comes along at a dangerous velocity, the mechanism controlled by the anemometer shuts off the power and applies the rail-clamps instantly.

Another important provision in the operation of this bridge is the magnetic switch controller or automatic skew-limit device. With everything in its normal position, both ends of the bridge will travel in the same direction at the same speed unless one end is retarded by wind effects, friction or dragging rail grips. In case one end does lag, the skew-limit slows down the leading motor until the ends are again even. By proper manipulation of the master switches, either end may be operated in either direction without danger of skewing too much because the automatic device assumes control when one end lags more than 22 ft. behind the other. Inasmuch as the flexibility provided in the bridge design would permit one tower to move approximately 65 ft. ahead of the other, there is left a wide margin of safety and certainty in operation.

Figure 11. View of coal piles and bridge from south end.

The Historical Development of

SMELTING *and* REFINING Native Copper

By H. D. Conant*

WITH the beginning of copper mining in the Lake Superior region of Michigan about the year 1847, a new feature was introduced into the metallurgy of copper. Before that time copper had been obtained from sulphide or oxide ores by a smelting process that involved several operations for separating the metal from the sulphur, iron and other impurities with which it was combined in the natural state. The product of the Lake Superior mines is native copper, and no complicated processes are required to prepare the metal for use in industry; it is necessary only to melt the concentrates and massive copper, remove the slag formed by the rock in which the copper is found, and then, by a simple refining operation, to prepare the metal for pouring into the various shapes required by manufacturers. Both melting and refining were formerly performed in the same furnace, but as practice has improved, the two functions have been separated and are now generally performed in different furnaces.

When the Lake Superior copper mines began operation, the concentrates were shipped either to the Revere Copper Works near Boston, or to the copper smelter at Baltimore where the sulphide ores of the Atlantic states had been smelted for many years; but in the year 1850, owing to dissatisfaction with the quality of copper produced at those works, and in order to reduce expense, four of the largest copper rolling and brass manufacturing companies in Connecticut joined in constructing a copper smelting works at Detroit, Mich., of which the present Calumet and Hecla smelter is a direct outgrowth.

At the Detroit works there were at first one small reverberatory furnace for smelting the concentrates from the mines and refining the copper and one small cupola for recovering the copper contained in the slag taken from the reverberatory furnace. The maximum furnace charge of refined copper was limited to about 16,000 lbs., while today charges of 600,000 lbs. are common. In 1861 a copper smelting works was built and put in operation on the shore of Portage Lake, opposite Houghton, in the mining district of Michigan. The equipment was of the same type as at the Detroit works and one description will apply to both.

The reverberatory furnaces were used for melting the mineral, as the concentrates from the stamp mills at the mines are called, and the massive copper which ranged in size from pieces weighing a pound or less to some that weighed ten or fifteen thousand pounds. The concentrates and smaller masses were shipped to the smelter in barrels—thus giving rise to the term "barrel work" for the smaller pieces. At the smelter the barrels were emptied on the floor alongside the reverberatory furnace and the concentrates shoveled into the furnace by hand, while the heavy masses were lifted by hand-operated jib cranes and lowered into place through a large opening in the top of the furnace. Charging the furnace was usually done during the afternoon and the melting was accomplished during the night; the slag formed by the portion of crushed rock that remained in the concentrates and mass was skimmed from the furnace as the charge melted, and by morning the furnace held only clear molten copper ready for refining. Following the old Welsh methods, the first step in refining was to remove impurities by oxidation, called rabbling. This was accomplished by forcibly splashing the copper up into the air with a rabble—a hoe-like implement with a 4 by 6-in. blade and a long iron handle. While the impurities were being oxidized in this manner, they formed a slag that floated on the surface of the charge and could be easily skimmed off. As some copper oxide was formed in this operation, the next step was accomplished by burying the ends of hardwood poles in the copper, permitting the carbon in the wood to unite with the oxygen in the copper which left the latter in a pure metallic state. On the completion of refining, the copper was poured into molds of various shapes, some for small ingots used in brass making, some for flat

* Superintendent of Smelter.

square cakes for rolling into sheet copper, and some for bars suitable for drawing into wire. The ingot molds made of copper and the wire bar moulds made of cast-iron were set on the edge of a tank of water into which the cast copper, after solidifying, was tipped and cooled. The cast-iron cake molds rested on the floor and were deep enough to permit five or six cakes to be poured, one on top of the other, each cake being allowed to solidify and chill slightly before the next was poured. After the cakes had cooled they were pried apart with chisels. The copper was dipped out of the furnace by men with small long-handled iron ladles holding from 15 to 20 lbs. each; these were carried across the floor and their contents poured into the molds. In pouring a flat cake, which might weigh between 150 and 300 lbs., from four to eight men, according to the size of the cake, stood around the mold with filled ladles poised ready to pour the copper simultaneously at a given signal so as to completely cover the bottom of the mold at one pouring; other ladlers followed in quick succession until the full thickness of the cake was attained. This method, inefficient as it was spectacular, has passed into history.

In 1886 the Calumet and Hecla Mining Company, whose product had for 20 years been smelted at the Portage Lake smelter, built a plant of its own near its stamp mills on Torch Lake. This was followed in 1888 by the erection of a somewhat similar plant at Dollar Bay on Portage Lake by the Tamarack and Osceola Mining Companies, which companies were later consolidated with the Calumet and Hecla. At neither of these plants was there any departure from the old established practice and equipment; reverberatory furnaces of the conventional size and type were housed in each of the four corners of dimly lighted stone buildings.

The first radical change from the simple furnace refining of lake copper was made in 1894 by the Calumet and Hecla Mining Company at its branch smelter erected at Buffalo, N. Y., in 1891. At that place an electrolytic plant was constructed for the purpose of purifying the copper obtained from reverberatory slag and for recovering silver from that portion of the concentrates that carried it in paying quantities. The cathode product and the richer grades of mill concentrates were melted together, resulting in a copper product of higher electrical conductivity than could otherwise have been obtained without excessive furnace treatment. The size of reverberatory furnaces was gradually increased from time to time until they had a capacity of about 30,000 lbs. of copper; but aside from the introduction of the electrolytic treatment, no change in method was made until 1898 when, at the Dollar Bay smelter a reverberatory furnace measuring 40 ft. in length was built for melting concentrates, with provision for drawing off the slag and accumulating within the furnace molten copper that was permitted to flow by gravity at intervals of from 8 to 12 hours into one of the existing smaller furnaces for refining. At this same time casting machines were built and installed. In these machines the copper molds were supported by cast-iron plates provided with rollers and connected by link belt chains that passed over sprocket wheels at each end of the steel frame forming the body of the machine. At first the copper was dipped from the furnace and poured into the molds by means of ladles holding from 100 to 150 lbs., which were suspended from overhead trolleys thereby permitting them to be moved in and out of the furnace and swung over the molds by hand. Later these ladles were superseded by larger ones operated by hydraulic power and into which the copper flowed direct from the furnace by gravity.

This practice of melting in one furnace and refining in another proved so successful that three additional melting furnaces of about the same size and type were built, the only difference being that in the latter the charge holes in the top were located along the sides, permitting the concentrates to protect the side walls from attack by slag and heat and thereby greatly reducing furnace repairs. This is the first instance on record of side wall charging, a process patented by others many years later and which has resulted in much litigation.

At the Buffalo plant in 1900 a reverberatory melting furnace in connection with a refining furnace, having a capacity of 100,000 lbs., was built and equipped with a Walker circular casting wheel permitting a charge of copper to be poured in less than a quarter of the time consumed previously and at much less cost. In the same year a second and larger electrolytic plant was built with a daily capacity of 40 tons, both this plant and the earlier one being arranged on the multiple system of deposition. With an ample supply of cathodes available, it was the practice to melt them in the refining furnace, the mineral being charged into the adjacent melting furnace from which molten copper was drawn, flowing through a spout from one furnace to the other to supplement the cathode copper already melted in the refining furnace. Several of the furnaces were at the same time provided with waste heat boilers, and an appreciable amount of steam was obtained at low cost to aid in the generation of electric current for the electrolytic plant.

In 1905 the practice of using sodium carbonate and lime to lower the arsenical content and raise the electrical conductivity of copper was introduced at the Dollar Bay works. A mixture of soda ash and lime in equal proportions was thrown over the surface of the furnace charge during the oxidizing stage of refining, forming a slag in which the oxidizing arsenic was absorbed and with which it was skimmed out of the furnace. This proved to be effective and less expensive than the former practice of using cathodes in the charge in order to dilute the arsenic, especially if the copper from which the cathodes were made did not contain enough silver to pay for the electrolytic treatment. The use of soda ash for this purpose has continued to the present time; but instead of shoveling it over the surface of the copper as at first, it is now blown through iron pipes into the copper below the surface, thus assuring more intimate contact with the arsenious oxide.

Early in 1914 the feasibility of burning pulverized coal in the reverberatory furnaces was considered as a factor of economy and efficiency, the use of that type of fuel having been general for many years in the cement industry and since 1912 for copper smelting in Canada. The advantages of burning coal in this form appeared so pronounced that it was decided to apply the system at the Dollar Bay works; but since powdered coal had not as yet been tried anywhere in the refining of copper, an expensive pulverizing plant was not considered advisable and a unit pulverizing mill of the type used in cement burning was chosen for the experiment. The trial was successful from the beginning, for not only was the melting accomplished readily, but the refining resulted in a more even grade of copper than had ever before been attained. Later on when the designs for the improved and enlarged reverberatory furnaces at the Hubbell works were made, there was also provided a capacious and efficient central pulverizing plant completely equipped for drying, fine grinding and distribution of powdered coal by means of compressed air to storage bins at each furnace.

In 1914 the Buffalo works were closed and all operations were transferred to the Hubbell works on Torch Lake where a new electrolytic plant of five million pounds a month capacity had been built, which would operate under the favorable condition of a low electric current cost owing to the utilization of exhaust steam at the stamp mills for generating power. Two 100-ton reverberatory furnaces, each of 200,000 lbs. holding capacity, had also been built and equipped with Walker casting machines and were used principally in the preparation of anodes for the electrolytic plant. The latter was closed in 1922 because of the lowering of silver values in the copper and the fall in the price of silver. These furnaces and their equipment were inadequate for making cakes and wire bars, while the constantly increasing proportion of low grade concentrates presented a problem in melting for which the existing furnaces were unsuitable. Plans were made accordingly for the construction of a large reverberatory melting furnace to melt all of the concentrates and deliver molten copper to the refining furnaces, and for enlarging and deepening the latter so as to hold as much as 600,000 lbs. of copper at a time. In connection with these improvements it was planned to replace the small casting machines with large Clark type wheels capable of handling copper at the rate of over 100,000 lbs. an hour. The completion of this construction marked the end of the transition from the laborious, expensive and inefficient methods of early times to the economical and efficient procedure of the present day.

This transition period has seen the passing of the blast furnace used formerly to smelt the slag that was skimmed from the reverberatory furnaces, during both the melting and refining stages, and to recover the copper carried by the slag in the form of silicate. Numerous attempts had been made to prevent copper from entering the slag while melting the mineral, but success was reached only after the application of pulverized coal. Now a slightly reducing atmosphere is maintained in the melting furnaces while oxidation of metallic copper is prevented by mixing coal or coke screening with the charge. This permits the immediate discard of the slag from the reverberatory melting furnace without further treatment; and as the refining slag can be effectively cleaned of copper in the melting furnace, the blast furnace has become unnecessary.

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Figure 1. General view of the Calumet & Hecla's Smelting Works

Present Smelting Practice

By
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and
Herman C. Kenny†

THE smelter is situated on the shore of Torch Lake about a mile from the Calumet and Hecla stamp mills. Torch Lake connects with Lake Superior by way of Portage Lake, thus affording an easy means for shipping copper by lake steamers and for receiving supplies. Rail shipments are made via the Mineral Range or the Copper Range railroads, which have connections with the Calumet and Hecla system.

Concentrates from the stamp mills are received at the smelter in standard-gauge bottom-discharge cars and are taken to the concentrates storage building. Mass copper from the mines as well as from the mills is received on flat cars and taken directly to the furnaces. The concentrates storage building is built with 10 large concrete bins, into which the concentrates are dumped from the cars. These bins, as shown in the diagram, are each 48 ft. long by 22 ft. wide by 21 ft. deep, and each provides storage capacity for 2,000 tons of concentrates, or a total available capacity of 20,000 tons. The steel framework for the building and the crane runway is carried on the bin walls. A traveling crane runs the full length of the building and is equipped with a 2-yd. bucket for reclaiming and mixing the concentrates. See *Figure 2.*

The gangue associated with all concentrates from the conglomerate lode except the flotation concentrates is ferruginous, whereas the amygdaloid gangue is silicious and contains considerable alumina. The flotation-concentrate gangue is not only silicious but high in alumina as well. The problem involved in bedding concentrates is to get an intimate mixture of the several varieties and grades in such a manner that the resulting product is self-fluxing. No fluxes are added to the concentrates before melting, but about 5 percent of coal or coke screenings is included in the mixture. Two classes of material are made from the concentrates by mixing—a rich mixture carrying about 75 percent copper and a low-grade of about 40 percent. The reason for this procedure is that the melting furnace is called upon to deliver a melted charge sometimes daily and sometimes less frequently, and by using the proper mixture the demand can be properly met. The operation following melting is so regulated that both mixtures will be used up in the proper proportion. Each mixture is bedded with coal in a separate bin and is mixed after each addition of new material by picking up the new concentrates with the grab bucket and dropping them in a different part of the bin, several times if necessary. See *Figure 3.*

Copper oxide from the ammonia leaching plants is stored in a separate bin and mixed with about 8 percent of coal screenings in the manner described. Fluxes—such as limestone, which is used with the mass copper—charcoal briquettes, sand, and other bulk supplies are stored in a second set of 10 smaller bins adjacent to the concentrate bins. One of the large bins is equipped with a filter bottom and an overflow for dewatering granulated slag from the refining furnaces. In a tunnel below both series of bins there are railroad tracks for

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† Metallurgist.

Figure 3. Interior of concentrates storage building

Figure 4. Scale car with charge leaving concentrates storage building

serving the furnaces. Concentrates are drawn off from the bins through gates into 150 cu. ft. scale-cars for charging. Scale car with charge leaving concentrates storage building is shown in *Figure 4*.

In considering the furnace operations, it must be borne in mind that the present furnace plant is an outgrowth from several units which preceded it, and, although a new plant would be somewhat differently arranged, the present equipment does very well indeed for the purpose. There are also several operations involved in the practice of smelting lake copper which do not conform to those used in matte smelting. For this difference there are very good reasons, although they are not always apparent. Except for the copper oxide from ammonia leaching, the entire metal content of the concentrates is native copper. The copper is too low in silver to warrant electrolytic refining and contains no gold whatever, and there are no other impurities which can not be removed by fire refining. A map of the smelter is shown in *Figure 5*.

The smelting operation consists of three essential steps: (1) melting, by which the metal is released and the gangue is removed as slag, (2) refining—that is, the removal of impurities by oxidation and slagging, followed by the reduction of the excess oxide by poling, and (3) casting the refined metal into shapes.

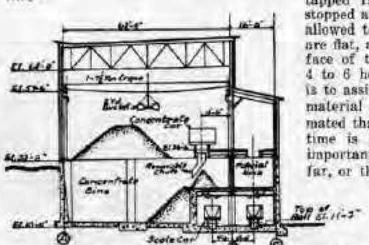

Figure 2.

The melting operation is carried out in a reverberatory furnace fired with pulverized coal. This furnace is equipped with tapping openings for slag on one side near each end and with a tapping slot for copper on the opposite side near the burner end. The wet furnace charge is brought from the concentrates storage building in scale weigh cars, which are hoisted with a crane and overturned into storage bins over the furnace. There are eight of these bins in line, made large so that the greater part of the concentrate handling can be done on the day shift. The furnace is charged from these bins through openings in the center of the arch. Center charging is practiced in lake copper melting furnaces, and is, no doubt, the most effective method under the circumstances. The practice is to charge a certain number of holes every two hours, or at longer intervals, depending on the rapidity of melting at the various points along the furnace. While the charging is going on, slag is being drawn off more or less continuously, starting from 4 to 6 hours after the first charge, or as soon as the slag becomes sufficiently fluid. The furnace atmosphere during the melting period must be kept slightly reducing. The reducing atmosphere, together with the coal screenings mixed with the charge, prevents oxidation of the metallic copper and subsequent loss of oxidized copper in the slag. At a time roughly 14 hours before the copper is to be tapped from the furnace, charging is stopped and the piles of concentrates are allowed to melt down. Before the piles are flat, air is introduced below the surface of the bath for a period of from 4 to 6 hours. The purpose of the air is to assist in bringing up the unmelted material from the bottom. It is estimated that about 7 hours of the melting time is saved in this manner. It is important not to oxidize the bath too far, or the slag losses will be high; but the material rising from the bottom brings up a mass of coal screenings with it and as long as a blanket of fine coal remains on the surface of the bath, the danger of oxidation is slight. Slag is not drawn off while the air-blowing is in progress. After the blowing is stopped, the slag is allowed time to separate, and the tapping is then resumed. From 2 to 4 inches of slag is allowed to remain on the bath and the copper is tapped from beneath it. The reducing atmosphere in the furnace causes the copper bath to retain a certain amount of iron and sulphur in solution, but the oxidation removes a considerable part of the iron.

Analysis of Melting Furnace Copper

Cu	98.7%
Fe	1.0%
S	0.2%
As	0.04%

The slag formed in the melting furnace would not be considered very desirable for a matte furnace, but it is quite fusible at a sufficiently high temperature. The following is an approximate average slag analysis for normal operation:

	Percent
SiO_2	42.5
FeO	30.0
Al_2O_3	13.0
MgO	2.3
CaO	8.0
Cu	0.60

As the slag leaves the melting furnace it is granulated in water and pumped 1,800 ft. through a 6-in. pipe line to the waste slag dump. Two pumps in series are used in this operation. Samples of the slag are taken automatically as it enters the second pump sump.

The smelter has learned from bitter experience that it is necessary to have sufficient spare furnace capacity to replace any unit on short notice. Therefore two furnaces for melting are available. The newer melting furnace, No. 20, is larger than the older furnace, No. 23, and is more advantageously placed. The intention is to use No. 23 as little as possible, but it must be kept in readiness in case of serious trouble with the newer furnace, such as a bottom replacement. No. 20 furnace is so located that

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the molten charge of copper can be drawn off through brick-lined, cast-iron launders 50 or 60 ft. long to either of two refining furnaces located near it. Copper from No. 23 furnace must be carried to the refining furnaces in 10-ton ladles. A photograph of the interior of melting furnace No. 20 is shown in *Figure 6*.

Molten copper is not so easily handled as matte. In the first place, its melting point is much higher, and, unless it is heated considerably above the melting point, it will not run in the launders without freezing. The melting range of copper is so small and its heat conductivity so great that skulls will form rapidly if the melt is at all cold. Once skulls begin to form, it is usually good business to stop tapping immediately, but to do so is always very difficult and sometimes impossible if a very heavy cut has been made. For this reason, it has been the custom to melt practically the entire charge and allow the bath to heat up before tapping copper. It is very difficult to raise the temperature of the bath much above the melting point while unmelted copper still remains in the furnace. Attempts have been made to draw off copper while there were still piles of unmelted concentrates in the furnace, but these trials usually have been abortive. The density of the molten metal is so great that just about the time when tapping is to begin one of the piles will come off the bottom and the unmelted material will spread over the surface of the bath and chill the copper. If the piles are high enough to prevent them from rising, the bath will be too cold to tap. Attempts to obviate the expensive run-down operation are still being made and may prove successful. In drawing off copper under the slag layer, it is customary to chill the slag near the tapping opening by charging small amounts of concentrates at that point; the slag is then held back by a clay plug and copper is tapped from beneath it.

The construction of the melting furnace is shown in the accompanying sketches and photographs. All furnaces are equipped with water-cooled cast-iron side plates to prevent breakouts. Skewbacks and charge-hole jackets are made of deoxidized copper and are also water-cooled. Water-cooled arc-welded steel dampers are used in all flues except after boilers. Some damper slots are also water-cooled. Circulating water is supplied from Torch Lake by centrifugal pumps.

Furnace foundations of melting and refining furnaces are of solid concrete except for longitudinal and transverse tie-rod ducts. Furnace bottoms are inverted silica brick arches, 18 or 20 in. thick. Under the bottom proper is a secondary inverted silica brick arch, usually 9 or 12 in. thick. The form of the inverted arch usually consists of brickbats or furnace concrete. Burned-in silica or sand bottoms are unsuccessful in Lake Superior practice.

The life of the brick work depends entirely on the production rate. At full capacity it is necessary to do some repair work, such as renewing a portion of the arch or patching the walls, every six weeks. These repairs usually entail a shutdown of not more than one or two days, which does not materially interrupt the operation of the plant. At three or four-month intervals a longer repair is necessary; the maximum lost time for a very extensive renewal of walls and arch would not be over one week.

Bottom renewals are a different affair. A bottom should last two years or more. The difficulty of removal depends upon the length of service. When a furnace bottom has to be renewed, the task of cutting out the old bottom is quite arduous. Since the bottom is thoroughly saturated with copper and can not be chipped out to advantage, underground mining methods of handling mass copper are resorted to. The old bottom is drilled with longitudinal and transverse rows of 1-in. diameter holes about 2 in. apart, the drilling being done with air-operated twist drills. These holes are charged in lots of 25 to 50 with 90 percent blasting gelatin, the whole is covered with sand bags and old rope, and the bottom is blasted out in sections.

The average daily capacity of No. 20 furnace when operating at full load is about 280 tons of concentrates, which will yield about 120 tons of slag. At this rate of firing about 75 tons of coal per day will be burned. The holding capacity of the furnace is roughly 500 tons of copper. Both melting furnaces are equipped with automatic damper reg-

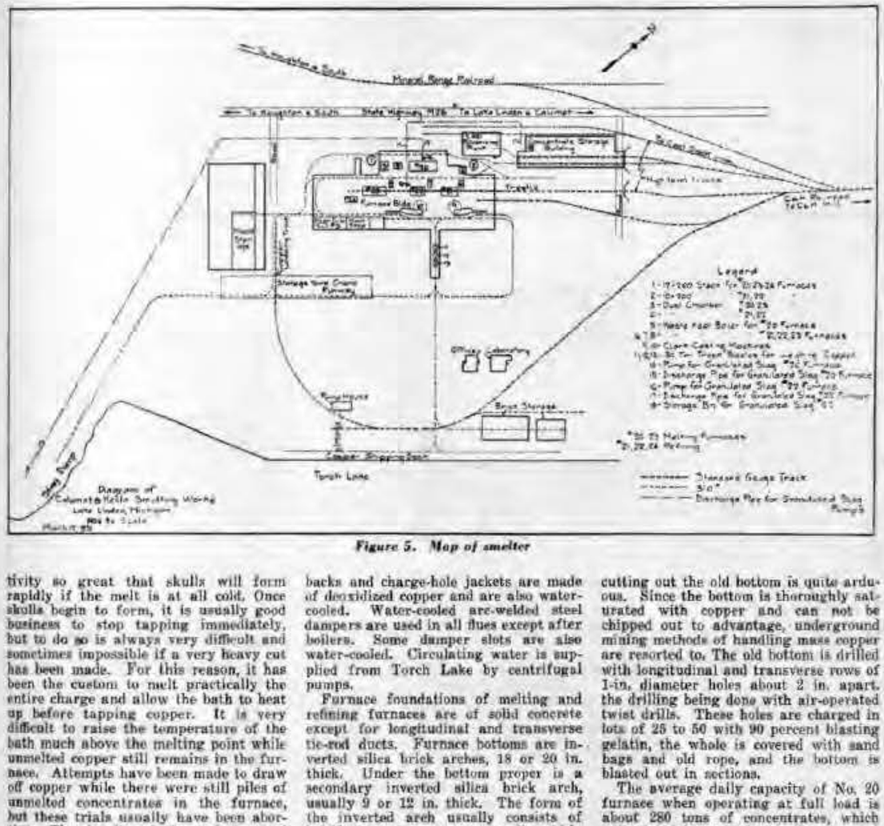


Figure 5. Map of smelter

Figure 6. Interior of melting furnace No. 20

ulation and automatic carbon-dioxide recorders.

Cost of Melting Furnace Operation

	Per Ton of Concentrates
Attendance	$0.22
Fuel (Pulverized Coal)	1.57
Supplies	0.28
Motive Power — Crane — Tramway	0.06
Repairs—Labor	0.11
Repairs—Refractories	0.24
Handling Furnace Charges	0.32
Total Melting Cost	$2.80

The metal drawn from the melting furnaces is run to one of two refining furnaces of the standard type. These have a capacity of from 250 to 450 tons of molten metal, depending on whether the bottom and sides are new or very much worn. Either of these furnaces can be run at a rate sufficient to care for the entire production of copper in normal times. One is a spare for the other, and as nearly as possible they are duplicates. The construction of the refining furnaces is similar to that of the melting furnaces. The main differences includes the elimination of the "verb" and the use of jackets instead of bottom tie rods for binding the ends of the refining furnaces. See diagram of refining furnace No. 22 in *Figure 7* and a section through No. 20 and No. 21 furnac in *Figure 8*.

In addition to the molten charge, co per oxide from the leaching plants handled by these furnaces. Since t oxide is very corrosive to brick work, is customary to protect the bottom a sides of the furnace, especially near t tapping slot, with a blanket of rich co centrates. This material is charged in the furnace, together with whatever r fining scrap or scrap molds or mine ma is available, before the molten charge run in from the melting furnace. Sma mass copper is charged directly into t melting furnace through a chute pr vided for the purpose, but the larg pieces are charged into the refining fu naces through a covered water-cool opening in the arch. To prevent expl sions of the copper oxide, which can quite serious, or in any event, spectac lar, it is necessary at least to partly me the charge already in the furnace befo adding molten metal.

As soon as the molten charge is in t furnace, oxidation of the bath with a commences. Compressed air is intr

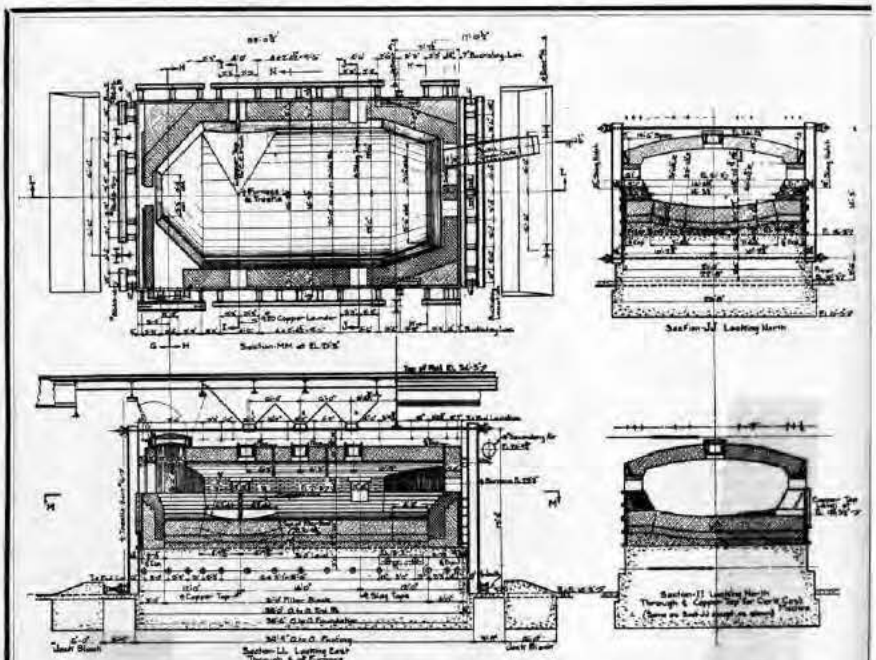


Figure 7

duced under the surface of the bath through iron pipes covered with a refractory cement. This is done at as many points as possible so that the charge will be fully oxidized by the time it is completely melted. In order to remove the iron and sulphur as rapidly as possible, the oxidation is carried further than in refining cathodes. During the oxidizing period, the iron removed from the bath would ordinarily form an infusible slag on the surface, but the charge is rapidly analyzed for iron before refining and a sufficient quantity of sand is thrown onto the bath to flux the iron oxide as it is liberated. This treatment results in a very fluid slag which is skimmed off, granulated in water, and pumped to the filter bin in the concentrates storage building. There it is dewatered, mixed with coal screenings, and added to the melting furnace charge. A Hummer screen is provided before the slag pump to remove from the granulated slag brick and unmelted lumps, which are always present in varying amounts.

All the furnace charges contain arsenic which may be removed to meet electrical-conductivity specifications after the iron and sulphur have been eliminated. The removal is accomplished by blowing powdered soda ash into the bath. The soda forms a fluid slag which absorbs arsenic readily. The soda slags, being very corrosive, must not be allowed to remain on the bath too long.

After the arsenic is removed, or even while it is being removed, poling is started to reduce the excess oxygen in the bath. Green hardwood poles are used in the poling process. The oxygen content of the bath is reduced to 0.04 to 0.05 percent, which is about right for tough pitch copper, and the metal is ready for casting.

In casting the copper, the metal is drawn off from the furnace into tilting ladles which supply the molds. The molds are of cast copper and are placed on a casting wheel of the Clark type, which has a capacity, depending upon the shape cast, of from 80,000 to 140,000 pounds per hour. The operation is continuous. As soon as the metal has set in the mold it is automatically dumped into a water bosh, and is removed from the bosh by a pan conveyor onto an inspection table, also a part of the conveyor system, where imperfections are removed by chipping and where imperfect castings are discarded.

Figure 9. Clark casting wheel

Refining Costs

	Per Ton of Copper
Attendance	$0.40
Fuel (Pulverized Coal)	0.57
Poles for refining	0.32
Fluxes	0.45
Other Supplies	0.17
Motive Power—Crane—Tramway	0.08
Handling Slag	0.14
Repairs—Labor	0.25
Repairs—Refractories	0.53
Total	$2.91

Copper molds are made on hydraulic mold presses, either water-cooled copper or cast-iron cores being used. Copper for these molds may be conveyed from any of the three refining furnaces to the presses either by means of crane-supported ladles or direct by gravity.

The multiplicity of shapes required by copper consumers necessitates tying up an immense stock of copper in molds. Wire bars are made in all sizes and flat cakes, wedge cakes, and slabs of many varieties must be produced as called for. Mold storage presents a problem. Molds must be readily accessible for the casting machine and still can not be allowed to occupy valuable space. A building formerly used for electrolytic tank house has been remodelled and serves very well for storage purposes. It is not uncommon to have 5,000,000 pounds of copper on hand as molds. See *Figures 9, 10* and *11* for photographs of casting wheel, inspection and mold storage.

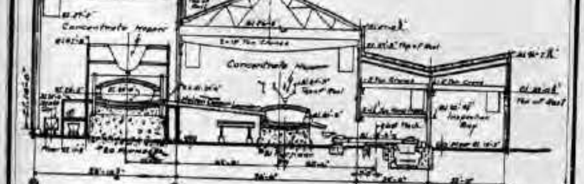
From the inspection table the cast shapes are loaded on narrow-gauge flat cars, weighed, and taken either to the smelter dock for lake shipment or to a storage yard served by overhead cranes. From the storage yard the copper may be loaded into railroad cars by means of a crane and an electric lift truck.

Cost of Casting Refined Copper

	Per Ton of Copper
Operating Labor	$0.40
Supplies and Power	0.08
Inspecting and loading copper	0.41
Making New Molds—Labor	0.09
Making New Molds—Supplies	0.09
Total Casting Cost	$1.07

In addition to the regular refining furnaces there is a furnace of about 75 tons capacity equipped for trolley-ladle dipping. This small furnace was built for casting billets and for making up small orders of special shapes which could not be made economically at the larger furnaces. The furnace operates intermittently as orders for billets accumulate. It is so arranged that a large opening in the arch can be used for charging unusually large pieces of mass copper and sections of old furnace bottoms.

All furnaces are fired with pulverized coal. The coal pulverizing plant is centrally located and the coal is blown from a weigh tank in batches of five tons to bins serving each furnace. The coal plant is equipped with a single roll



Section Through #80 and #81 Furnaces and Casting Machine Looking North

Figure 8

Figure 10. Copper inspection

Figure 11. Mold storage

crusher, magnetic belt separators, 100-ton crushed-coal bin, Ruggles-Coles doublepass dryer, and two Raymond six-roller mills. A washer and a Dracco filter are used to remove dust from the drying and grinding systems respectively. The building was designed to provide for duplication of drying and grinding units if the necessity should arise. The coal burned is a very good grade of high-volatile bituminous, having an ash content of from 3 to 6 percent, sulphur always below 1 percent, and a heating value of from 14,200 to 14,700 B. t. u. per pound. Since the moisture content is very low, in summer it is sometimes possible to dispense with the drying operation. In winter, on account of the snow on the stock piles and coal cars, drying is always necessary. An effort is made to keep the moisture content of the pulverized coal below 1 percent. The fineness varies from 75 to 85 percent through the 200 mesh, depending upon the condition of the mills. Pulverizing costs are slightly over $0.50 per ton of coal.

All furnaces are provided with waste heat boilers which can be by-passed if necessary. The melting furnaces have dust chambers following the boilers. These melting-furnace boilers are arranged for pulverized coal firing in case a furnace should be shut down and additional steam should be desired. The waste heat boilers on the melting furnaces give very fair performance records in spite of the heat taken up in the furnace. Evaporations of 7 to 1 from and at 212 degrees F. are not uncommon on the total coal burned in the furnace. The gas temperatures entering the boiler may be as high as 2,300 to 2,500 degrees F. and those leaving the boiler will be about 600 degrees. Steam is used for running an 800-kw. turbine generator and for other miscellaneous steam-driven equipment and also for heating the buildings in winter.

Three brands of copper which are classified by arsenic content are produced at the smelter. Typical analyses of these three brands are given in an accompanying table.

The standard specifications of the American Society for Testing Materials for low resistance Lake copper are the same in all particulars as those for electrolytic copper. Prime C&H is used in all sizes of wire for electrical purposes. On account of its inherent high native purity, toughness, ductility, and tensile strength, prime C&H sheet and strip copper enjoys popularity in the trade for many uses, such as washing machines, automobile radiator cores, and refrigerators.

Typical Analysis of Three Brands of Copper

	Prime C&H Percent	Natural C&H Percent
Copper plus Silver	99.9500	99.9100
Arsenic	0.0025	0.0445*
Iron	0.0025	0.0025
Nickel	0.0015	0.0015
Sulphur	0.0015	0.0015
Oxygen	0.0420	0.0400
	100.0000	100.0000

CL percent arsenic varies in CL grade from 0.06 to 0.50. Other impurities same as other grades.

* Arsenic may vary from 0.02 to 0.06.

Natural C&H and C L brands are specified for architectural work, owing to the increased strength and resistance to corrosion imparted by the arsenic. This metal is also used in European practice for locomotive fireboxes and staybolts.

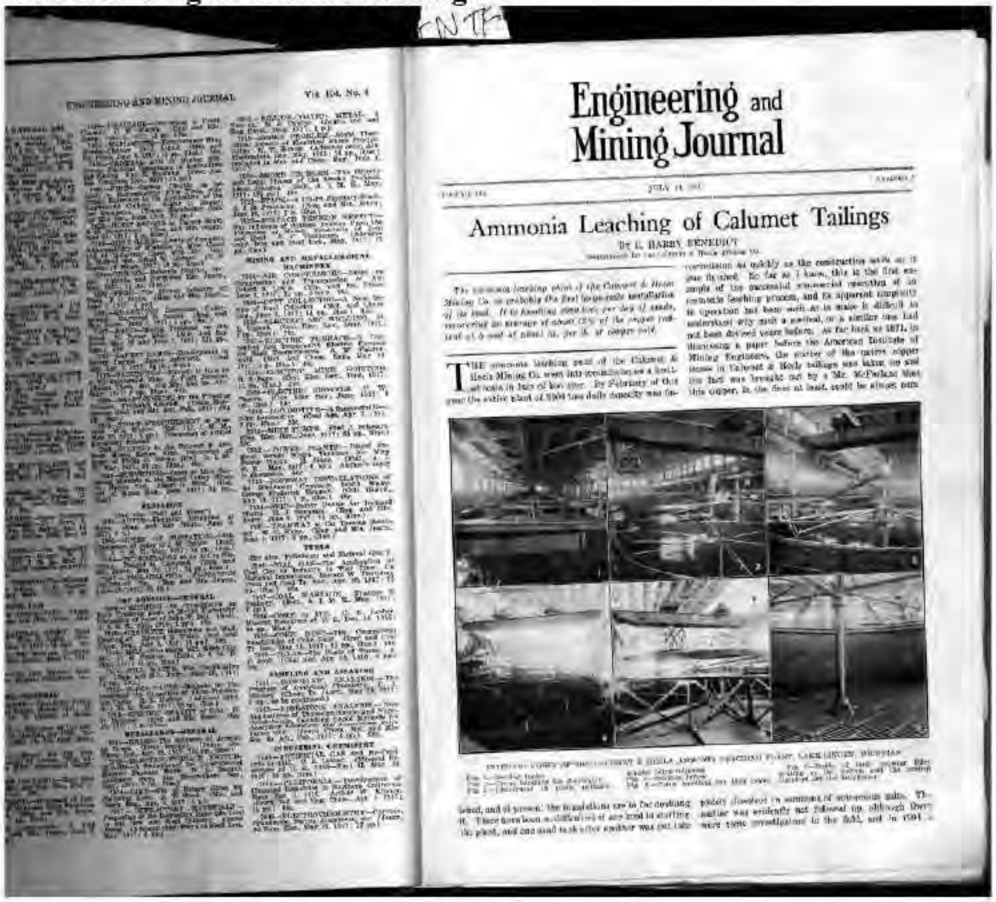
In addition to these brands some metal is sold on the basis of silver content. High-silver Calumet & Hecla copper, which maintains its strength at high temperatures, is used for special purposes where this requirement must be met.

Figure 12. Loading copper for rail shipment at storage yard

Figure 13. Loading copper for Lake shipment at copper dock

4.3.2 Engineering and Mining Journal

Ammonia Leaching of Calumet Tailings



Engineering and Mining Journal

Ammonia Leaching of Calumet Tailings

By C. HARRY BENEDICT

patent was issued to Ernest A. LeSueur, of Ottawa, for an ammonia process, and in his patent description he mentioned the Calumet & Hecla sands. This patent was called to my attention about two years ago, and Mr. LeSueur and myself did a little work on the matter; and while it was evident that it was easy to get the copper into solution, we were not able to hit upon any method that seemed feasible for getting back the copper after once it was dissolved.

The matter was dropped entirely until the fall of 1912. At this time, having occasion to familiarize myself with the distillation of ammonia products, the idea occurred to me of using this method of recovering copper from solution. A test of the process on a laboratory scale at once gave great promise, and it was not long before a [illegible] plant was in operation. This plant only tended to confirm results obtained on a smaller scale, and the next step was to build a 20-

the chemistry of the process. Oxide of copper or native copper with the free access of air, dissolves in ammonium carbonate to form cupric ammonium carbonate, probably according to the following reactions:

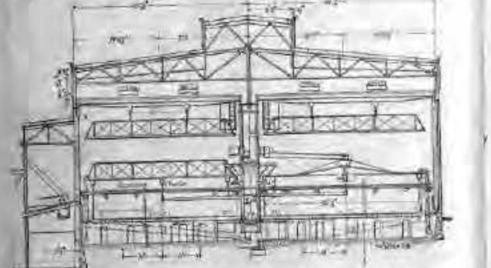
$$Cu + O = CuO$$

$$CuO + (NH_4)_2CO_3 = CuCO_3 \cdot 2NH_3 + H_2O$$

This cupric ammonium carbonate, in the presence of native copper and without free access of air, is reduced to the cuprous state, as follows:

$$CuCO_3 \cdot 2NH_3 + Cu = Cu_2CO_3 \cdot 2NH_3$$

The cuprous ammonium carbonate in the presence of air oxidizes rapidly to the cupric state, and as such is capable of dissolving a further amount of copper. Now either the cuprous or cupric ammonium carbonate, when subjected to boiling or distillation with steam, loses its ammonia and carbonic-acid gas, both of which can be absorbed in water and recovered, and as these are driven off, the cuprous or cupric oxide is thrown



SECTION SHOWING THE TANK ARRANGEMENT OF THE CALUMET & HECLA REACTION PLANT

ton plant. This too proved successful and while there were many things that could not be proved in a plant of this size still the apparent cost of the operation was so low and the margin of profit indicated so large that we felt we could take a chance on many of the doubtful factors and begin the construction of the full-sized plant. The decision to go ahead with this work was made in the spring of 1914, and the contracts for much of it had been let when the European War broke out. The unsettled condition of affairs caused the company to cancel these contracts, and it was not until toward the end of the year 1914 that we had sufficient financial courage to go ahead. Work was begun in earnest in the spring of 1915, and thanks to good deliveries of material, the plant was in partial operation within 10 months of the time ground was broken for the foundations.

Before giving a detailed account of the process as finally applied, it may be well to give briefly some of

out of solution either as a heavy powder or as a scale, according to this reaction:

$$CuCO_3 \cdot 2NH_3 + H_2O + Heat = CuO + (NH_4)_2CO_3$$

If these reactions are followed through, it will be found that the solvents are quantitatively regenerated and that the only consumption of a chemical element is that of oxygen from the air. Not only is this theoretically the case, but it was demonstrated in the experimental work on Calumet conglomerate ore that these reactions did take place about as indicated and it was possible to make a recovery in the laboratory of practically 100% of the ammonia. This was done, however, by heating the tailings after the copper had been dissolved and the acid washed—an operation which of course is impracticable. The amount of ammonia remaining in the tailings before heating was small enough to assure the economic possibilities of the process.

It will be observed from the reactions that the solvent is cupric ammonium carbonate and that this is reduced

to the cuprous state in dissolving the native copper. To reoxidize this solution and restore its solvent power, only oxygen of the air is used, and the success or failure of the process depends upon the ability to oxidize the solutions quickly and without loss of ammonia. It is impossible to work entirely in inclosed vessels because to do that would prevent oxidation, and on the other hand to work entirely in open tanks is impractical not only because of the smell and discomfort, but also because it is almost sure to result in excessive loss of ammonia from volatilization. In working with a single tank, as was done in the experimental plant, it is easy to get sufficient oxidation of the solution by superficial action in the storage tanks, for the cuprous solutions have a great avidity for oxygen, and since the cupric salt formed is heavier than the cuprous, convection currents are set up that aid materially in the complete oxidation of the cuprous solutions. It was realized that in a large plant where the effluent solution from one tank would be in storage for only a limited time before being used again as a leaching solution, there would be much less opportunity for oxidation. However, this was worked out as the size of the plant increased, and we have found it a simple matter to oxidize the leaching solutions by blowing air through them and to absorb what little ammonia gas is driven off with the air in a weak solution. This particular feature, which

continuously would require a type of still different from anything on the market, and we set about making our own apparatus. We started out with a still consisting of twelve cylindrical sections, each 15 in. in diameter and 6 in. high and with a vertical shaft extending the full length of the still fitted with a scraper for each section. The general principle of operation was similar to that of any continuous still, the solution passing downward from section to section against the ascending current of steam. This apparatus demonstrated that any scale of copper oxide formed could be handled by means of these scrapers, and a second still, 56 in. in diameter, was built, followed by the present commercial stills 84 in. in diameter. They have a capacity of over 150 cu.m. per day of copper ammonium carbonate solution assaying about 20 grams NH_3 per liter, and the same in copper.

The material treated in the present leaching plant consists of mill tailings as free from copper as the mechanical processes and water concentration will permit. A part of the material comes from the current tailings from the mine rock and a part of it from corresponding tailings that have been in Torch Lake for many years. No matter what the source, the material had been originally put through 3/16-in. screens in a steam stamp and is now further ground in pebble mills to pass a 20-mesh screen. This product is then concentrated upon

SOME TANKS PARTIALLY FILLED

COMPLETION OF SAND FILLING

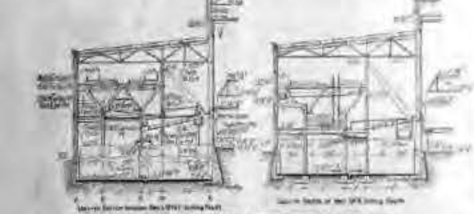
[illegible] AND VALVES

caused the most concern in experimental work, was thus easily met at the plant developed.

The other matter that caused a good deal of difficulty in the experimental work was the boiling-out of the solution. The oxide of copper as it was thrown down in the laboratory was a very fine powder which settled rapidly. It was hoped that on a large scale this powder might stay in suspension with sufficient agitation and then settle into a pocket and be easily removed by means of a trap discharge. What was actually found, however, was that while a part of the oxide could be handled by the foregoing methods, that part of it which had an opportunity of becoming superheated, as it would above the solution level, formed a scale so hard that it could be removed with nothing short of a hammer and chisel. It became evident that in order to distill this cuprous ammonium carbonate

Wilfley tables, and it is the tailings from these tables that enter the leaching plant. In this leaching plant the feed, or loading, is sent to 16 V-shaped settling tanks, each 10½ ft. long, 10½ ft. wide and 8½ ft. deep. The overflow from these settling tanks contains practically all minus 200-mesh material and is at present a waste product, although plans are under way to treat it by flotation. The thickened product from these V-tanks is drawn off by means of plugs and fed to eight quadruplex Dorr classifiers, the slimes from which go to waste and the sands to leaching tanks. This classified product is an ideal one for leaching, and while it carries some slimes, it has not been found necessary to [illegible] any of the precautions sometimes taken in sand-leaching processes for eliminating all traces of colloids. There seems to be no serious obstruction to a satisfactory leaching rate.

FWTF



90% of the copper content of the liquor is deposited in this still, which we call a roughing still, and is trapped off into a chamber that is discharged periodically directly into a filter box and from this loaded into concentrates cars. The other 10% of the copper remains in solution or suspension and passes through a second still of a standard type, which we call a finishing still, and from which the final solution, barren of ammonia, runs into a settling tank to permit the settling out of the copper oxide. There are two roughing stills connected in parallel, as to solution and steam, with one finishing still, and the rest of the distillation unit is made up of a reflux column, condenser, etc. The oxide of copper as precipitated by this operation will assay about 80% copper and is practically pure. It goes direct to the smelting works, where it is mixed with the native copper concentrates, and as such, since it is free from gangue, it is highly prized by the smeltery men, since the oxygen it contains aids in slagging off the impurities of the rest of the charge.

As at present operated, the daily capacity of the leaching plant is 2000 tons. The plant is run by three shifts of eight men each, and in addition to these there are six men on the day shift for repair work, the bulk of which is in connection with the stills. These with the head chemist make up the working force. Allowing an average rate to these men of $2.50 per day, there is indicated a labor cost of 3c. per ton of material treated. The repairs will be very slight, judging from the ten months of operation of the plant. The wear and tear on Dorr classifiers is not appreciable as yet, and the same is true of the sand distributor. Centrifugal sand-pump liners give some trouble, but nothing that cannot be easily handled on the Sunday morning shutdown. There has been no evidence of corrosion in the cast-iron solution pipes or in the leaching tanks. The strong liquor as received and the distillate made is somewhat corrosive, but hardly sufficient to warrant a protective lining. Fortunately, the extent of this strong-liquor line is limited and its maintenance will not become laborious. The amount of electric power consumed in the plant is equal to 225 kw., most of it being used in the operation of sands pumps which, on account of the local conditions, are numerous, since it is necessary to pump the mill tailings into the leaching plant, to pump the sands from the Dorr classifiers to the leaching tanks and also to pump the tailings from the plant back to the lake. The steam for distillation amounts to about 35% by weight of the liquor distilled and, as now operating, costs about 4c. per ton of sands treated. The greatest single item of expense is the ammonia, the loss of which is just under one pound per ton of sands treated. Under ordinary economical conditions this ammonia should not cost over 15c. per lb., but at present, owing to the excessive demand, the cost is almost double that figure. The complete record of cost for March is given in the accompanying table.

COST OF AMMONIA LEACHING

	Per Ton
General expense, including insurance and chemists	$0.011
Ammonia	.153
Sand excavating and classification	.029
Labor, power and supplies for leaching	.023
Steam for distillation	.018
Labor and supplies for distillation	.033
Total cost	[illegible]

During this month there was a recovery of 5.18 lb. copper per ton of material treated, giving a cost per pound, up to smelting, of just 5c. For the first four months of the year the cost per pound of copper has been less than 4.75c. up to smelting, or about 6c. per pound sold. The present production is at a rate in excess of six million pounds per year.

The extraction varies with the fineness of the product, which as far as the leaching plant is concerned, should all be through 48-mesh, but which actually is very much coarser. As operating at present, there is some 28- and 48-mesh material on which the extraction is less than 60%, whereas on the material passing through the 150- and 200-mesh the extraction is as high as 85%. The average extraction is now about 75%. The data in the accompanying table are for April.

SANDS LEACHING PLANT, APRIL, 1917

Size of Sand Particles	Feed % Sand	Feed % Cu	Tailing % Sand	Tailing % Cu	% Extraction
On 28-mesh	3.6	0.707	3.3	0.416	29.7
28- to 48-mesh	15.3	0.619	16.9	0.214	65.4
48- to 100-mesh	44.0	0.607	46.0	0.136	77.6
100- to 200-mesh	34.2	0.571	23.1	0.094	83.7
Through 200-mesh	4.9	0.594	10.8	0.114	88.5
Average for month—total		0.644		0.141	78.1

The process was originated and developed entirely by Calumet & Hecla engineers. The mechanical details were designed by H. E. Williams and Robert MacIntosh, with helpful suggestions from Allan J. Clark, of the Homestake Mining Co. The general design of the plant and the chemical development of the process was taken care of by the writer and H. C. Kenny, the latter now in charge under Henry Fisher, mill superintendent.

Dividing a Mortar-Box

By Charles Labbe
Mechanical engineer, [illegible], Nev.

In the case where a five-stamp battery mortar-box is to be divided to provide two smaller boxes or where the division is necessary for other purposes, the following method may be adopted:

With the mortar-box in its normal position a line is traced around the outside and inside, at the required distance from one end, with cold chisels, then deepened to a groove about [illegible] in. deep. The position of the mortar-box is then reversed and the base of the sole-plate divided in a similar way with a cold-chisel cut and, later, with a cape-chisel groove [illegible] in. deep by [illegible] in. wide, beveled on both sides with a cold chisel. A crack is then started from the top of the mortar-box where the thickness of metal is less by means of blows from a hammer on a chisel held in the groove. Two and a half sticks of 40% powder are then firmly pressed into the groove across the sole-plate and the cap placed in the center on the top of the powder, the whole being covered with soft clay and sand to act as tamping media for the exclusion of air. Half a dozen old dies are then piled on the tamping and the fuse is lighted. The explosion will result in the division of the mortar-box along the lines traced by the cold chisels, but possible damage and injury from falling dies must not be overlooked.

In the case in point it was found necessary to construct a two-stamp battery from a five-stamp mortar-box and equipment. The method outlined proved successful for the division of the mortar-box, the only difficulty present, and the rough edges of the exposed side were afterward chipped and filed to allow the placing of a heavy sheet of iron which was attached by means of cap-screws in the ordinary way.

British Engineers

THOMAS KIRKE ROSE
[illegible] of the British Mint, Author of "The Metallurgy of Gold," and a distinguished authority on that subject.

F. W. HARBORD
[illegible] associated with the British iron and steel industry, and of wide experience and high attainments in general consulting practice.

Developments in Lake Superior Milling

Copper Ore-Dressing and Leaching Practice—Two Types of Ore Necessitate Different Methods, Of Which the More Complicated Includes Stamping, Regrinding, Tabling, Leaching Of Sands by Ammonia Solutions and Flotation of Slimes

By C. H. Benedict
Metallurgist, Calumet & Hecla Mining Co., Calumet, Mich.

AS IS WELL KNOWN, two principal types of copper ore are mined in the Lake Superior region, both of which contain native copper, but which differ materially, not only in the physical character of the gangue but also in the physical character of the contained copper. The conglomeratic ore is a hard, close-grained rhyolite, characteristically composed of pebbles, and in which the copper forms the cementing material in the interstices between the pebbles. In the amygdaloidal ore, on the other hand, the copper occurs in more massive form than in the conglomerate and the rock is much softer.

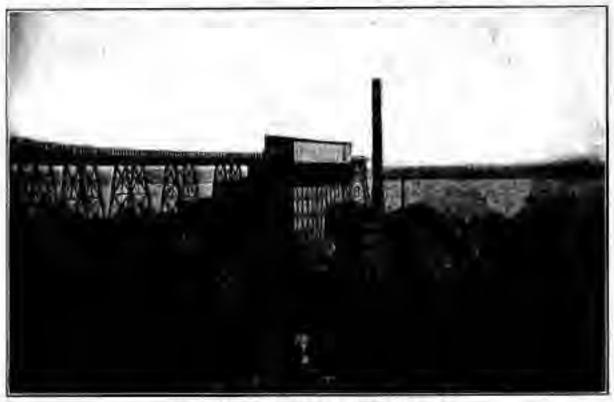


FIG. 1. AHMEEK STAMP MILL, HUBBELL, MICH.

Numerous amygdaloidal lodes are being worked, and each lode differs to some extent from all the others, both in physical characteristics and in rock constituents, and more particularly as regards the richness of the ore and the size and distribution of the copper particles. The only conglomerate ore mined at present is from the Calumet & Hecla mine, and, inasmuch as the lode is rich and the copper is in a fine state of subdivision, metallurgical development has been more pronounced in the treatment of this "rock" than in the case of any other "rock" in the district.

The question of the best metallurgical treatment of the amygdaloidal ore is most often a compromise between the possible metallurgical recovery and of the economics of that recovery. That is to say, though it is possible to get a high metallurgical recovery, because of the nature of the ore and the general simplicity of the metallurgical treatment, it is not always economical to carry that recovery to its highest point, as the additional value is not warranted by the increased cost incurred. The richest ore now milled in the Lake Superior region comes from the Champion mine of the Copper Range Co., which throughout 1918 gave a recovery of 36.6 lb. copper per ton of ore milled, with a tailing loss of probably six to seven pounds per ton. The lowest-grade ore profitably milled in the district during the same year was from the Kearsarge lode of the Osceola Consolidated Mining Co., which yielded only 12.62 lb. per ton, with a tailing loss of less than four pounds.

It is obvious that it is possible to carry the metallurgical treatment of ore further when one is treating material assaying 40 lb. copper per ton than would be possible with corresponding material assaying but 16 lb. copper per ton. If one is inclined to criticize the lack of fine grinding or some other relatively crude method prevailing in some mills, one must take into account the fact that the value of the fine copper may not be present in sufficient amount to warrant a better process. The amygdaloidal ore mined by the Isle Royale Mining Co., for example, contains a large percentage of heavy copper, so that it is possible to make a recovery of more than 80 per cent by stamping it in a steam stamp and screening it to a maximum size of $\frac{3}{16}$ in. without the necessity of finer grinding of the $\frac{3}{16}$-in. material. On the amygdaloidal ore of the Kearsarge lode, and also on that of the Pewabic lode, the metallurgical recovery is not nearly as good for the same degree of crushing. To get satisfactory results it is necessary to resort to regrinding of the coarser tailings.

Copper Is Coarser in Amygdaloidal Lodes

In all of the amygdaloidal lodes the copper is in a coarser state of subdivision than in the Calumet conglomerate. Thus, to release the mineral values, it is necessary in the case of the Calumet conglomerate to grind to a finer size than for the amygdaloidal ore. The big problem for the metallurgist is not so much to devise a method of saving the copper when liberated as it is to decide to just what extent he is justified in going into the matter of saving. His judgment in this respect must be based on many factors, some of which are within his control and some of which are not. The equipment that would have been justified at 25c. copper would not be economical at 15c. copper, and, in the same way, an equipment that would be justified for a given price of copper for a given quality of ore might, in turn, not be justified in case the ore became two or three pounds leaner. That is the reason for a statement made earlier in this article that the complexity of treatment and the choice of the flow sheet are, to a great extent, a question of the value of the copper per unit of ore.

One feature that must be clearly understood in any review of the metallurgy of Lake Superior is the influence of the presence of coarse metallic copper, because of the fact that it is metallic and therefore not subject to subdivision at the will of the operator. As is well known, one may have masses of metallic copper underground of almost any size up to hundreds of tons' weight, but as the ore comes to the mill the largest masses of copper have been cut up and one must reckon with pieces that might be contained in rock of the maximum size of, say, 12 by 12 by 14 in. in dimensions. It is because of the possible presence of masses of copper of this size that the automatic feeding of stamps has not been practiced in the Lake Superior region.

It would be easy to devise a feeder for a stamp that would maintain the proper load in the mortar, and many efforts have been made in this direction, but until some one can devise a plan whereby the large masses of copper can be automatically removed from the heads at the same time, there will be no saving of labor in having the automatic feeder, because it is essential to have an attendant present at the feed shoot to remove the large masses of copper. If they get into the mortar they may cause serious damage, such as the breaking of the shoe, stamp stem or piston rod, and if they do not do this they will accumulate in the mortar to such an extent as to make necessary the removal of the grates and the shoveling out of the mortar contents. This refers to masses of copper eight or ten inches in size.

Provision has been made for the removal from the mortar of masses up to three or four inches in size by means of two devices patented in about 1900 independently by F. E. Woodbury, now deceased, and by Charles and Henry Krause. The devices are known as mortar discharges and have for their object the removal of coarse copper from the mortar, for which purpose they are most effective.

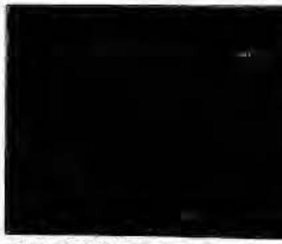


FIG. 1. OLD REGRINDING PLANT OF THE CALUMET & HECLA MINING CO.

FIG. 2. PRESENT REGRINDING PLANT OF THE CALUMET & HECLA MINING CO.

The Krause discharge is a plain hydraulic discharge opening into the mortar through the staves at a point about five inches below the level of the bottom of the mortar grate. The Woodbury device also operates through the staves, but at the level of the bottom of the mortar grate, and is in the nature of a jig with a pulsating current, as opposed to the constant hydraulic pressure used in the Krause discharge. These two devices are effective in removing from the mortar such copper as may be within their range, which is roughly from 1 up to 4 in. in size, and any copper coarser than this should be removed by the stamp attendant, or "head feeder," as he is locally known. It is the presence of these large masses of copper that makes it impracticable to use a gyratory crusher or even coarse rolls for the preliminary crusher, and the steam stamp has been unique and unchallenged for this purpose.

It is not only on account of the size of the copper that the steam stamp is so efficient, but also, strange to say, because of the shape of the copper. This is really worth consideration, as those who operate mills in the Lake Superior region find a great deal of confusion of ideas on the part of the sulphide-ore operators in respect to the last-named feature.

Before the days of flotation the most common criticism heard of Lake Superior practice was the opinion that the steam stamp caused too much abrasion and consequent loss of copper. To anyone who has tried to abrade copper, and then at the same time attempted to crush amygdaloidal rock, the fact would quickly be forced home that the rock will slime while the copper still remains in its original form. Further than this, it is really necessary that the copper be somewhat "punished" before it is given jig or table treatment. A great part of the copper is in such shape that the surface is out of all proportion to the mass, and by the action of the stamp it is either hammered into a more compact body or is subdivided into a number of pieces each more compact than the original. This matter of the shape of the copper particles becomes much more important in the finer states of subdivision, where forces other than gravity have freer play.

In the early days the inefficiency of the metallurgical process was recognized just as keenly as it is at present, but there was no form of fine grinder that was sufficiently cheap in operation to warrant its installation on these relatively low-grade ores; more particularly so because, even with the release of the copper particles from the ore, their recovery was problematical.

Use of Rolls Not Successful

The use of rolls for fine grinding was not a success and could not have been a success, because they simply crushed the particles of rock and released the copper in its original shape, which ordinarily is so pronged and irregular that it could not be saved on a vanner or on a Wilfley table. The same general effect occurs with the Huntington mill, the crushing action of which is similar to that of a roll. The effect of the shape of the copper was definitely recognized by the early operators, who attempted to use grinding devices that would put the flat copper particles into more of a pellet form. For this reason the old Herberle grinder found great favor in the Calumet & Hecla mills before the days of the Wilfley table, because its action was such that the copper was rolled up into a globular or pellet form which was easily saved by a jig.

At present a crushing device is being developed which it is confidently believed in some quarters will accomplish the same result. The device is known as the Lovett grinder. It is a horizontal disk grinder, one of the disks having an oscillating and the other a circular motion, so that the grains of rock are torn apart and the copper is rolled up into a more compact form than it originally had in the ore.

It was not, however, until the introduction of the Chilean mill, taken in conjunction with the Wilfley table, that it was possible in the Lake Superior region to obtain an economical recovery of copper from particles finer than $\frac{1}{16}$ in. The Chilean mill had not met with great favor in Western practice, because of its sliming proclivities, which made it, on the other hand, acceptable to native-copper metallurgy. The copper freed by the Chilean mill was in the shape of flat grains and was in excellent condition for a good recovery by the Wilfley table. Up to the time of the introduction of the pebble mill, the Chilean mill was the only type of fine grinder used generally in the Lake Superior region, and it found a place in the stamp mills, not only of the Calumet & Hecla Mining Co. but also of the Copper Range, the Mohawk, and the Lake Milling Co.

With the introduction of the Hardinge grinder, which fortunately occurred at about the same time that cheap power became available, owing to the adaptation of the low-pressure turbine to the utilization of the exhaust steam from the stamps, fine grinding may be said to have secured an established place in the metallurgy of the Lake Superior district. Each important plant now has one or more mills in operation, and each operator has attempted to find the economical point to which this fine grinding can be carried on his particular ore under the varying conditions of the copper market.

In the Isle Royale plant, which has a capacity of about 2,000 tons of ore per 24 hours, one mill is in operation, regrinding middlings from the jigs and tables; and this seems to be about the proper practice for the ore, as it contains a large percentage of the copper in coarse particles. In most of the mills treating amygdaloidal ore, however, the practice is to have at least one pebble mill for each stamp unit of 700 tons' daily capacity. This might be termed "standard" practice for medium-grade amygdaloidal ores.

The Champion and the Baltic mills of the Copper Range Co. stamp the highest-grade amygdaloidal ores in the Lake Superior district, and in both there are a sufficient number of ball mills in use to regrind all jig tailings. The Quincy plant has two Hardinge ball mills in operation and is now installing five Marcy ball mills for the regrinding of its jig tailings.

On the conglomerate ore of the Calumet & Hecla Mining Co., there are sufficient pebble mills in operation to regrind all jig and table tailings so that the product passes a 28-mesh screen and about 40 per cent passes 200 mesh. In all of the plants the product of the ball and pebble mills, with little preliminary classification, is treated on Wilfley tables, and a recovery of from 35 to 60 per cent of the copper is effected. The resultant tailings in all mills except those treating conglomerate ore is sufficiently low in copper to throw away. Only in the mills of the Calumet & Hecla does further metallurgical treatment follow the tables.

Calumet & Hecla Conglomerate Ore Contains Finely Divided Copper

The conglomeratic ore of the Calumet & Hecla Mining Co. is in a class by itself, because of the fact that, as stated earlier in this paper, the copper is in a fine state of subdivision and also because the ore is richer than any of the amygdaloidal ores except the product of the Champion and the Baltic. The pebble mill regrinding followed by table treatment still left copper amounting to seven or eight pounds per ton, and it was realized that the limits of mechanical separation had been reached.

Efforts had been directed for many years to find a leaching method that would recover the copper commercially, and finally, in 1912, a process was invented by the author[1] which solved the problem. The leaching plant has now been in operation three years, and has been an entire success. For 1918 there was recovered 8,035,156 lb. refined copper from the treatment of 1,005,-015 tons of sand, at a cost, excluding smelting and selling, of 7.71c. per lb. This showed a copper recovery of about 75 per cent on the material treated by leaching, and brought the recovery on the original ore up to better than 90 per cent. The cost of the leaching operation is about 40c. per ton under normal conditions, which would necessitate a grade of ore assaying at least six pounds per ton before one could hope to make the

[1] Eng. and Min. Journ., July 21, 1917.

FIG. 1. WILFLEY TABLES FOR WET TREATMENT OF [illegible]. FIG. 2. SEPARATION OF SLIME FROM LEACHING SAND BY DORR CLASSIFIERS. FIG. 3. LEACHING [illegible] PLANT SHOWING TANKS AND DISTRIBUTING LAUNDER. FIG. 4. SAND DISTRIBUTOR AND REMOVABLE LAUNDERS

process commercially available and, as most of the amygdaloidal ores of the district yield a tailing just under this, there does not seem to be much hope for the extension of the ammonia leaching process to such ores, although it is perfectly adaptable to them and will effect a good metallurgical recovery.

Flotation in Treatment of Copper Ores

The latest development in the treatment of Lake Superior ores is the adoption of the flotation process. The leaching process has been worked out only for the treatment of the sands, and flotation is so efficient for the treatment of slimes that it is not conceivable that the leaching process could compete with it, even were the many mechanical problems worked out that would arise in an effort to adapt ammonia leaching to slimes. None of the amygdaloidal mines has installed the flotation process as part of the mill practice, although the Winona mill had made a beginning toward this end at the time it was closed down following the signing of the armistice.

Both the Copper Range and the Quincy are doing some experimenting with flotation, but neither company has even an experimental unit in operation. At the White Pine mill, where the ore is neither conglomeratic nor amygdaloidal, but consists of sandstone and slate, flotation is part of the regular practice, and all the tailings are subjected thereto. In this mill, the flotation is applied to the ore following the table treatment and as a final process. The ore consists of copper in a fine state of subdivision in sandstone, and in an almost microscopic state of subdivision in slate, so that the mill recovery, previous to the introduction of flotation, did not exceed 60 per cent. Flotation processes effect a recovery of about 65 per cent on the material treated, so that the final mill recovery is fairly satisfactory.

It is on the conglomeratic ore of the Calumet & Hecla Mining Co. that the only flotation plant of any size is in operation. Up to the time of the introduction of flotation, slime practice had consisted of treatment of the pulp on round tables and of the concentrate produced by these on Wilfleys. This round-table Wilfley practice has now been discontinued, and the slimes, as they leave the Woodbury classifier following the stamp, are subjected to the action of a two-spigot hydraulic classifier, and the resultant spigot products are treated on Wilfley tables. The overflow of this classifier goes to a 25-ft.-diameter three-tray Dorr thickener, and the product of this thickener is treated in flotation machines of the Minerals Separation type. For each conglomeratic-ore stamp unit of 350 tons' daily capacity there is one

FIG. 5. FLOTATION PLANT OF CALUMET & HECLA

25-ft. thickener, and the thickened product from four thickeners, amounting to about 400 tons daily, is treated on a 24-in. Minerals Separation machine of 600 tons' nominal capacity. Of the sixteen cells of this M. S. machine, two are used for mixing only, and two for cleaning up the concentrates of the other twelve.

The concentrates go to a Dorr thickener, and from this to an Oliver filter, from which the material is scraped into the concentrate cars for treatment at the smeltery. The plant has been working for just about a year and indicates a recovery of about 65 per cent of the contained copper and at a cost of possibly 20c. per ton, including royalty. In addition to this plant of 2500 tons' daily capacity on the Calumet & Hecla conglomerate, a second plant of like capacity is being built, which is to treat the slimes resulting from the regrinding operations, both of the current tailings and of the tailings from the lake. This plant will consist of eight Dorr thickeners, 40 ft. in diameter, three-tray, and for the treatment of the thickened product will have four M. S. type machines of 600 tons' nominal capacity each. The plant should be in operation some time during the summer and will give a total flotation capacity of 4,000 tons. The capacity of the leaching plant is also 4,000 tons, so that the combined re-treatment plants will be able to handle the normal production of 6,000 tons daily of ore from the mine and 2,000 tons from the accumulated tailings.

With the successful working out of the leaching and flotation processes on native copper ores, the operator in the Lake Superior copper region has at his command all necessary means for good metallurgical recovery. Milling costs are low, and can be lowered by cheaper power resulting from a more general installation of low-pressure turbines, which have been found universally satisfactory. Grinding costs may be still further reduced by improvements in machines or methods. Neither jig nor table practice has been improved for some years, the re-treatment of the tailings from these machines making them of lesser importance than formerly. It is to the economics of the problem that the mill man must give greatest attention.

Report of Chile Copper Co.

Reserves, Production, Equipment, Improvements, New Construction—Twelve Shovels Are Now Operating—Leaching Recoveries High

THE third annual report of the Chile Copper Co., for the year ended Dec. 31, 1918, shows that 3,745,248 dry tons of ore was treated, averaging 1.64 per cent copper, the recovery from which averaged 82.17 per cent, or 51,068 tons of copper produced, compared with 2,905,186 tons treated in 1917, averaging 1.76 per cent, with recovery of 81.81 per cent, or 44,186 tons of copper produced. The positive and probable ore reserves as of Dec. 31, 1918, are estimated as follows: Oxidized ore, 336,510,349 tons, of 1.91 per cent copper; mixed ore, 161,000,000 tons, 2.98 per cent copper; sulphide ore, 210,000,000 tons, 1.84 per cent copper; total, 697,510,349 tons, 2.12 per cent copper.

In 1918, there was produced 102,136,658 lb. of copper, of which there was sold and delivered 84,695,259 lb., at an average price of 24.713c. per lb. of copper. The total cost of production was 17.885c. per lb. of copper sold, distributed as follows: Cost of production, including depreciation, selling, delivery, New York expenses, taxes, and less miscellaneous income, was 15.318c. per lb. Cost of plant and equipment installed in prior years and abandoned or superseded by other structures or machinery has been charged against the year's income, equivalent to additional cost of 0.049c. per lb. Depletion of mineral deposits has been charged against income at a cost of 2.518c. per lb.

OPERATIONS AT THE MINES

Ten hectares of ground situated along the northern border of the district were acquired for use as a dump site and railroad right of way. Only five prospect holes were drilled, with total footage of 942 ft. There was loaded, to be sent to the reduction plant, 3,401,627 metric tons of 1.71 per cent copper. A total of 557,900 cu.yd. of waste was removed from all benches, averaging 0.27 per cent copper. Underground development was advanced 34,721 ft. Since the beginning of the underground blasting tunnel development a total of 70,950 ft. of tunnels has been driven, of which 22,759 has already been blasted.

During the year, 1,458 holes were drilled, with a total footage of 58,268 ft. Since operations began, 3,812 holes have been drilled, with a total footage of 145,386 ft. The ground broken was 4,140,518 cu.yd. [illegible] has been taken from the dumps. The tonnage remaining in the several piles is 397,267 tons, averaging 3.65 per cent copper.

Twelve shovels are in operation, two of which are standard 100-C Bucyrus electric machines. These electric shovels are giving excellent service; their operation being in every way more economical than steam shovels. One Baldwin, seven Porter and thirteen [illegible] locomotives are in service attending shovels. Two more 100-C electric shovels have been erected and will go into service when main hoisting motors are received. One 225-B electric shovel is under erection and will be put into service within ninety days (report dated Feb. 5). Two 1,000 ft. motor-driven compressors were installed.

In the secondary crushing plant, the operation of rolls was discontinued early in 1918. The third section went into service on Mar. 31, and on July 2 a complete installation of eighteen fine reduction Symons discs were in operation. The feature of the completed disk installation was the gradual cutting down of the oversize on 3/8-in. screen. During the first quarter this oversize was about 50 per cent, whereas for the last quarter it averaged 16.6 per cent.

In the leaching division, the important feature was the increased extraction. An average of 87.8 per cent was reached, as against 82.2 per cent for 1917, owing principally to the finer grinding of the ore. The maximum was reached during November, when an average of 91 per cent was obtained.

The new de-chloridizing plant should be in operation before the middle of 1919, with greatly improved equipment. The feature here was the development of a cylindrical copper drum for precipitating cement copper, in place of the trommel.

The following were among the important additions to the plant equipment completed during the year: Symons crusher house, first west extension; solution sump; foundry and oxygen generation plant. The following features are well under way and should be completed early in 1919: sewage system and disposal plant; machine shops; [illegible] pipe line, and eleven-bay extension to electrolytic tank house. Progress in all construction work is still seriously retarded owing to difficulties in obtaining material on account of embargoes on exporting from the United States, as well as shortage of shipping facilities.

The average rate of exchange between Chilean currency and United States currency was 0.37 for 1918, as against 3.90 in 1917. This low exchange had the effect of increasing the payroll for native labor by $360,000 United States currency over what it would have been at the previous year's exchange.

The Record of Tax Receipts of the Ontario Government for the year ended Oct. 31, gives the total amount paid by mining companies as $663,547. The principal items are: Hollinger Consolidated, $70,453; International Nickel, $[illegible]; Nipissing, $84,927; Mond Nickel, $45,769; Kerr Lake, $34,400; McIntyre-Porcupine, $[illegible]; Miller Lake-O'Brien, $6,781.

Sealing Water in California Oil Fields

Productivity of Oil Formations Is Sometimes Seriously Affected by Water Penetration—Improved Methods of Sealing Water-Bearing Formations Have Been Devised

BY SETH S. LANGLEY
[illegible]

IN CALIFORNIA, all drilling operations are under the supervision of the California State Mining Bureau, which maintains an office in each of the principal fields. A definite procedure under supervision of the bureau is followed from the time of location of the well, while it is being drilled, and through its productive life to final abandonment. The purpose of this is to provide proper protection of the underground oil and gas resources. Each major operation is inspected, and either accepted or rejected, by a deputy inspector, and there has grown up a cordial coöperation between the bureau and the operators. The California State Mining Bureau should be congratulated for its persistent [illegible] and for the results that have been obtained.

Before describing the various methods of sealing water, or water shut-off, as it is more generally designated, it is necessary to present some figures to show the necessity of successful water control in the California oil fields. I am indebted to the California State Mining Bureau for some of the statistics given in Table I.

TABLE I. TOTAL OIL AND WATER PRODUCED BY ALL WELLS DURING FISCAL YEAR, JULY 1, 1917, TO JULY 1, 1918

Field	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]
Total and average	[illegible]	[illegible]	[illegible]

TABLE II. AVERAGE DAILY PRODUCTION

A—Average Daily Production of Fields in [illegible] County

Field	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]
Total and average	[illegible]	[illegible]	[illegible]

B—Average Daily Production in [illegible]

Field	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]
Total and average	[illegible]	[illegible]	[illegible]

C—Average Daily Production in [illegible]

	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]

D—Average Daily Production in [illegible]

Field	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]

The following figures in Table III, for Sections 4 and 5, Township 11 N., R. 23 W., S. B. B. M., and Section 32, Township 12 N., R. 23 W., S. B. B. M., illustrate the complex problems to be met in the Sunset field:

TABLE III. WATER AND OIL PRODUCTION [illegible]

Well No.	Zone	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Zone A, the uppermost oil horizon, is about 300 ft. in thickness, and has a water zone 50 ft. above it. The top of Zone A is about 2,600 ft. from the surface. Zone B, the top of which is approximately 100 ft. below the bottom of Zone A, has a thickness of 200 ft. There is a water zone between Zone A and Zone B. The top of Zone C, which is 400 ft. thick, is 100 ft. below the bottom of Zone B. There is a water zone with two water sands between zones B and C. The total production on Feb. 1, 1918, of oil and water from the three zones is shown in Table IV.

TABLE IV. TOTAL PRODUCTION TO FEB. 1, 1918, IN SUNSET FIELD

No. of Wells	Zone	Oil, Bbl.	Water, Bbl.	Water, per Cent
[illegible]	A	[illegible]	[illegible]	[illegible]
[illegible]	B	[illegible]	[illegible]	[illegible]
[illegible]	C	[illegible]	[illegible]	[illegible]

[illegible]

It would be expected that the failures to exclude water would be greatest at the greatest depth. This is found to be true, but Zone B has a greater percentage of success than Zone A, which lies above it. The explanation of this is that there is a more favorable structural condition between the water sand and Zone B than above Zone A and C.

It is readily seen from the conditions outlined that one of the most serious problems in California operations is the control of underground water. The operators have been fortunate in that the men who have been called upon to solve these problems have been drawn from all the fields of the world. Broad experience and the breadth of vision to meet new conditions with new methods or adaptations of old methods have solved many trying situations, and the outlook for future progress is encouraging. The technology of all branches of the oil industry is advancing, and none more rapidly than that appertaining to underground operations.

Four types of water must be excluded: top, intermediate, bottom, and edge. Top water is water

Calumet & Hecla Mining Co.

During the year ended Dec. 31, 1918, the Calumet & Hecla Mining Co. produced 67,968,387 lb. of copper. The production costs and earnings statement, as given in the annual report, is tabulated as follows:

PRODUCTION COSTS OF CALUMET & HECLA MINING CO. FOR YEAR ENDED DEC. 31, 1918

	Pounds	Per Lb.	
Mining and mine costs	52,722,969	15.41c.	$8,419,589.27
Reclamation	7,245,348	7.36c.	661,082.74
Totals	67,968,317	15.95c.	$9,481,584.81
Smelting, refining, Eastern offices and transportation costs		1.74c.	$1,395,151.71
Depreciation and depletion		5.14c.	3,609,214.93
Production cost of	67,968,317	21.84c.	$14,745,950.45
On hand Jan. 1, 1918	17,965,241	13.18c.	2,363,988.84
Total	85,933,558	19.23c.	$16,571,457.29
Delivered in year	78,567,544	19.29c.	15,114,714.63
On hand Dec. 31, 1918	7,366,014	19.29c.	1,456,742.66

EARNINGS STATEMENT

	Pounds	Per Lb.	
Received for copper delivered	78,567,544	24.18c.	$18,927,952.71
Costs of copper delivered:			
Production cost as above, at 19.29c.	$15,114,714.63		
Selling and delivery costs at 0.50c.	392,382.58	19.79c.	15,507,097.21
Gain on copper delivered		4.49c.	$3,519,755.56
Miscellaneous receipts	$2,139,291.74		
Miscellaneous charges	1,350,358.22		1,409,441.81
Total net income			$4,940,175.87
Dividends paid	$6,000,060.00		
Reserve (estimated) for 1918 Federal taxes	590,000.00		6,590,060.00
Balance			$1,350,883.91

Tons of rock treated aggregated 2,576,592, at a mine cost (excluding construction) of $3.07 per ton. The rock yielded 52,722,969 lb. refined copper, or 20.42 lb. per ton of ore mined. Of this production 1,647,803 tons came from the Conglomerate lode, at a mine cost of $4.09 per ton, and yielded 43,329,816 lb. copper, or 26 lb. per ton, and 1,328,789 lb. came from the Osceola lode, at a mine cost of $1.88 per ton, and yielded 15,888,168 lb. copper, or 11.68 lb. per ton.

Mine development on the Conglomerate lode included 28 ft. of shaft sinking, 7,149 ft. of drifting, and 3,550 ft. of crosscuts and foot-wall raises. On the Osceola lode, 10,192 ft. of drifting was performed.

Operation of the regrinding plants is illustrated by the following figures of tonnage treated and results obtained:

TONNAGE AND TREATMENT DATA

	From Mine	From Old Sands
Tons treated	[illegible]	713,897
Assay heading, per cent. copper	[illegible]	[illegible]
Assay tailings, per cent. copper	[illegible]	[illegible]
Pounds refined copper	[illegible]	[illegible]
Cost per pound, including smelting and selling	[illegible]	[illegible]

The leaching plant operated satisfactorily throughout the year, with the following results:

Tons treated	[illegible]
Assay heading, per cent. copper	[illegible]
Assay tailings, per cent. copper	[illegible]
Pounds refined copper	[illegible]
Pounds refined copper per ton treated	[illegible]
Cost per pound copper, excluding smelting and selling costs	[illegible]

The results of operations of the reclamation plant for the year are as follows:

	Year 1918	Since Starting
Tons sludge treated	[illegible]	[illegible]
Assay heading, per cent. copper	[illegible]	[illegible]
Assay tailings, per cent. copper	[illegible]	[illegible]
Pounds refined copper	[illegible]	[illegible]
Pounds refined copper per ton treated	[illegible]	[illegible]
Cost per pound copper, excluding smelting and selling costs	[illegible]	[illegible]

Dividends paid by the company to the end of the year 1918 (including No. 185), amount to $150,750,000. Dividends received from subsidiary companies to the end of the period reviewed were as follows: Ahmeek, $5,932,540; Allouez, $1,127,500; Centennial, $166,000; Isle Royale, $411,734.50; Osceola, $9,620,002; and Superior, $100,200; total, $16,968,076.50.

An Adjustable Motor Anchorage

An adjustable motor anchorage which is used for the purpose of conforming motors to their bedplates is illustrated herewith. It is suitable for use on motors of 50 hp. or over and recently has been placed on the market by the Adjustable Anchorage Co., of Detroit, Mich. The device is simple, reliable and positive, and its application to motors equipped with magnetic clutches is of particular advantage, although it is useful

ADJUSTABLE ANCHORAGE FOR MOTORS

on motor driving belts. Heretofore motors have not infrequently been doweled in place. Any change in the situation of a motor so positioned is difficult, slow, and often entails injury or destruction to the concrete foundation. By means of this new device slight changes in the position of the motor may be readily and quickly effected, the only tool necessary being a suitable wrench.

Injury to Blasting Employees

By A. L. H. Street

Attorney at law, 921 Security Building, Minneapolis, Minn.

In an action to recover damages for death of a mine laborer in the Joplin district, due to an explosion of dynamite used by him in breaking boulders, it is held by the Missouri Supreme Court that a mine operator may be regarded as having been guilty of actionable negligence in permitting an inexperienced man to use dynamite under such circumstances, without proper instruction, not only as to the dangers involved in the work, but also as to how he should do his work to avoid such danger. (Ruleval vs. American Zinc, Lead & Smelting Co., 207 Southwestern Reporter, 742.)

It is also decided that whether an employee is to be regarded as having been guilty of contributory negligence or as having assumed the risk of injury in such a case depends upon whether the peril encountered by him was so obvious that a reasonably prudent man would not, under the same circumstances, have undertaken the work, considering the injured man's experience or lack of it in such work.

Technical Training*

Special Knowledge Required by the Young Man Who Hopes Successfully To Meet the New Problems Which Have Grown Out of Recent Changes in Commercial and Industrial Activities

By W. L. Rogers

TO THOSE young men who contemplate a career in the petroleum industry—or, for that matter, in mining of any sort or in the diversity of industries that have to do with engineering in all its multiplicity of forms—thorough technical education is today of greater value than at any time in the past. Tomorrow it will be still more valuable, and its value will increase as the years pass.

The reason is simple, if we will but stop to consider and analyze the events of the last century. A hundred years ago our mineral wealth was practically untouched; the great West was an unknown wilderness; the revolutionizing inventions based upon steam and electricity were undreamed of. We were in large part a pastoral and mercantile people, untrained in the sciences which now form so vital a factor in our daily life. The great fabricating plants of all kinds that now dot the landscape from Maine to California were then unthought of; the family spinning-wheel supplied the wants now cared for by the factory equipped with intricate machinery. The homemade tallow dip afforded the light now supplied by electricity, gas, and petroleum; and the horse transported from place to place the freight we now move by railroad and motor. The infinite and complex activities founded upon power have necessitated special knowledge, and that knowledge is now in large part being supplied by our colleges and universities through engineering courses.

Science, after all, is but the record of experiments, successful and unsuccessful, which have been co-ordinated, catalogued, and filed away for future reference. It is the index, the record, of the activities of the practical man whose pioneer efforts in the field, the factory, and the laboratory are made available as a guide to posterity. And because of the complexity of modern engineering in all its branches, its constantly widening scope and growing literature, it is becoming more and more important that the young man upon the threshold of his career shall be familiar with past failures and successes, to the end that he shall not waste his time in attempting experiments long ago undertaken by others, the records of which are available for the asking.

None of us, I am sure, would think of submitting himself to untrained hands if in need of a surgeon, nor would he knowingly commit his cause to one untrained in the law. The case of the youth about to enter the oil industry is in a great degree parallel—no one would think of giving him the job of drilling the well, producing the oil and transporting, refining and marketing it, unless he had first undergone a preliminary course of education, had served his apprenticeship. This apprenticeship may be served entirely in the field, but if it is served first in the classroom and thereafter in the field the result will, of course, be more satisfactory. And, given two boys equally endowed, the one possessing the technical education should not only far more quickly complete his practical apprenticeship, but he would in after years be more completely the master of his chosen subject.

And, again, the reason is not far to seek; he has mastered not only the theory but the practice of his business; he knows not only what to do, but—and what is perhaps equally important—why he does it. I know, of course, that there are great men who have risen to eminent rank in their several professions without a college degree, but I think it may safely be said of them that they would have the sooner arrived, and would have saved themselves endless and laborious effort, if they had in the first place completed a technical course of training. The information slowly gathered in fragments here and there over the long years of practical apprenticeship could be far better mastered in four years of intensive training in college, where it is acquired in an orderly, co-ordinated, and complete way.

We must not fall into the error of believing that a college degree is a certificate of ability. Far from it. The world is well supplied with men possessing sheepskins whose services would be dear at any price. Without the requisite foundation of character, all the diplomas on earth will fail to make their possessor a man of value. Common sense, that greatest of all fundamentals, is often notable by its absence among highly educated theorists.

We are taking our discussion broadly upon the question as to whether or not a technical education is advisable for a young man about to embark in the oil business. In production, certainly, some geology as well as civil and mechanical engineering is of value. In transportation, mechanical engineering is almost a necessity; and in the refinery a course in chemistry is a prerequisite for any man who hopes to master the refining of petroleum in all of its branches and stand among the leaders of modern refining practices. I believe, too, that a salesman who knows something of the chemistry of oils, and who has served apprenticeship in a refinery, will, other things being equal, lead the way, rather than follow the lead of others.

All industrial activities should be constantly progressing. Inertia is fatal. And he who would lead or be near the head of the procession must of necessity have technical education as the foundation of his activities. He may not acquire it in college; it may come through the slow process of years of practical experience, but is it then the less necessary; and if four years will serve to acquire the fundamental knowledge that it would otherwise have taken fifteen or twenty years to gather, is it not the part of wisdom to adopt the former course?

There are many young men who have already started out in their work without having had the opportunity to secure the necessary technical foundation. I believe that those who can would do well to spend a year or more at some technical school, and with that groundwork build the balance of the structure by home study.

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