FROM ROCK TO ORE

How Mill 3 Worked

PAST • PRESENT • FUTURE

Once the miners had drilled, blasted, tunnelled, sweated, toiled and collected the muck (a mixture of valuable ore minerals and waste rock), it was sent to the Mill. Sending it to the Mill allowed the valuable ore minerals to be separated from the waste rock (called gangue) so that only the valuable ore was sent to the smelter. Sending only ore to the smelter was what made the mine managers happy. Therefore, the Mill was a crucial step in the whole mining process. And Britannia's Mill No. 3 was no exception.

Note: some of the years given here may not be accurate. Historical documents give some conflicting reports on when certain operations began and ceased. The most likely, or commonly used date has been reported here.

The Ore

The main ores recovered at Britannia were:

- Chalcopyrite: copper sulphide – for copper
- Pyrite: iron sulphide – for iron and sulphur
- Sphalerite: zinc sulphide – for zinc and cadmium (as impurities)
- Galena: lead sulphide – for lead
- Gold
- Silver

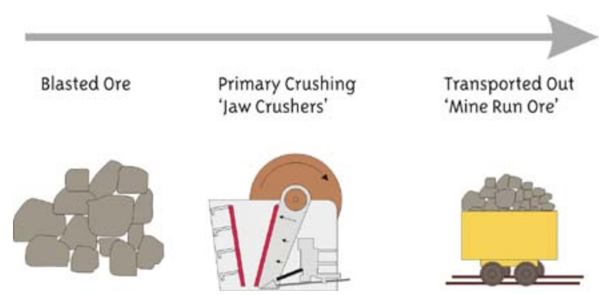
In the early years, only chalcopyrite, gold and silver were extracted. Mill operators calculated the amount of iron, sulphur and zinc present, but as there was no market for them at that time, pyrite and sphalerite were not extracted.

The Mill began extracting pyrite from 1924 though it was not always sold. It was either stockpiled at Britannia, or sold when it could be, for the production of sulphuric acid, pig iron and fertilizers. When stockpiled, this was because there was no market for it, and/or because there was no shipping space. Zinc production came later by 1935, again, when the market arose. Galena production came in by 1952.

Some of the changes over the years in the Mill reflected the changing mining operations, i.e. if the miners were targeting a particular ore body rich in a particular mineral.

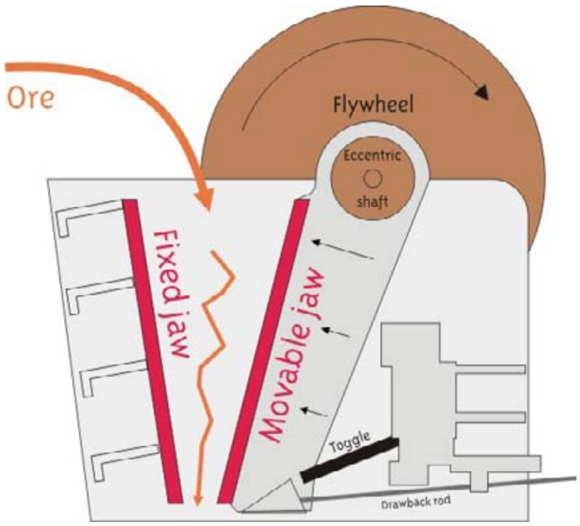
Underground

When the ore had been blasted, it was crushed to a manageable size underground, so that it could be removed from the mine without placing unnecessary wear on the transportation equipment, e.g. locomotive or conveyors. This stage is called Primary Crushing and is often done with Jaw Crushers; this was the case at Britannia.



Jaw crushers are designed to handle large blocks of ore. Ore is fed into the top of the crusher, and out from the bottom. There is a fixed jaw and a moving one (the swing jaw). A flywheel is fixed by a shaft to the moving jaw. As the flywheel rotates, it causes an elliptical motion which causes the moving jaw to move back and forward - crushing the ore against the fixed wheel. Each piece of ore falls down between the jaws as it gets smaller. It falls from the bottom of the jaws when small enough. Ore that is already small enough will fall through the crusher quickly.

Until the mid-1940s at Britannia, primary crushing was all one derground. However, by 1943, a jaw crusher had been installed in the Mill to



Jaw crushers handle large blocks of ore and are the primary crushing stage.

crush some ore from an ore bin that stored mine run material that had not been crushed underground; the increasing size of the mine made underground crushing cost-prohibitive. After going through the jaw crusher, it was added to the system along with the rest of the ore.

In the Mill

The ore was brought in on locomotives by the trestle railway at the top of the Mill. The ore (already crushed to 6 inches and smaller) was tipped into five giant ore bins at the top of the Mill, where it began its way down through the crushing, grinding, flotation and dewatering stages. Mill No. 3 was designed in the same design as Mill No. 2. However, it was not long before it was realized that the design would not be suitable, and the first changes were made within a matter of weeks.

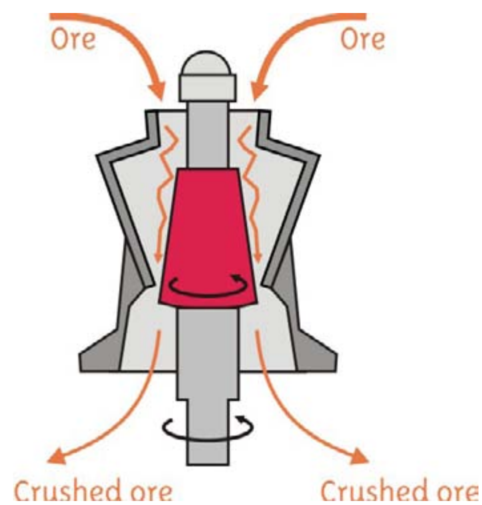
Crushing Stage 1 – Cone & Gyratory

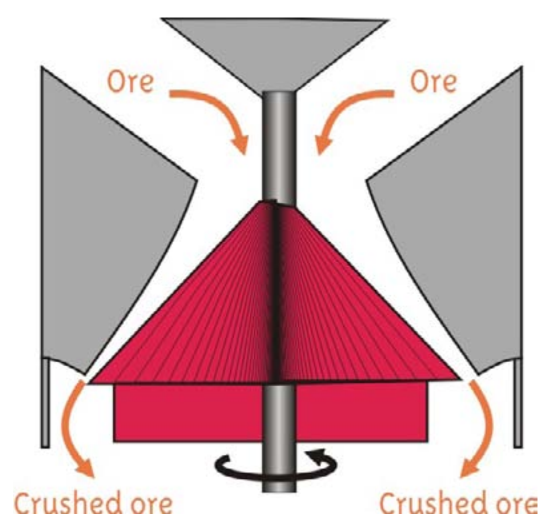
For its size, the Britannia Mine's community had Between the ore bins at the top of the Mill and the first of the crushers, the ore was fed over a Grizzly, a sorting device (series of metal bars spaced out and set on a slope) which lets small pieces fall through. The small pieces, called 'undersize' bypass the first crushing stage and go to the next (Roll) crushing. The bigger pieces go to the Cone or Gyratory Crushers.

Another important step before the first crushing was washing to remove the Primary Slimes (clays and mineral salts) that contaminated the ore and would otherwise clog up the system. During the 1930s the ore was even washed twice before it reached the first crusher.

In the 1920s, the first crushing in the Mill (technically secondary crushing as primary crushing was done underground) was done with Gyratory Crushers. This reduced the ore to ¾ inch sized pieces. Similar to Cone Crushers, these are large capacity crushers that can handle the large pieces of muck fed into them. By 1931, they had replaced the Gyratory Crushers with Cone Crushers.

Both Gyratory and Cone crushers work (below images respectively) on the principle of a gyrating (not rotating) inner cone, which crushes the ore against a static outer wall.

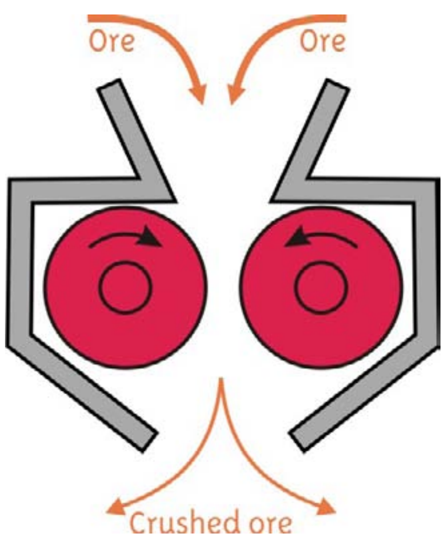




It is normal practice in the crushing process to run the crushers in shifts. Starting and stopping crushers do not lead to a loss in capacity time, unlike grinding and flotation processes. When not crushing, they could be maintained and repaired. At Britannia, in 1932, it was reported they were running on 20 hour shifts, processing 350 tons per hour.

Screening

After the Cone/Gyratory Crushers, the ore was screened (sorted) and sometimes washed too before heading to the Roll Crushers. The layout varied over the years, sometimes including washing screens, and sometimes only dry screens. Like Grizzlys, screens are used to remove the undersized pieces to send further on in the system. The dry screen favoured at Britannia was the Hummer Dry Screen. This used electromagnetism to cause the screen to vibrate (like a stereo speaker). The screens were sloped, so as the ore passed over it, vibrating as it went, smaller pieces fell through its mesh and larger pieces carried on to the next crushing stage.



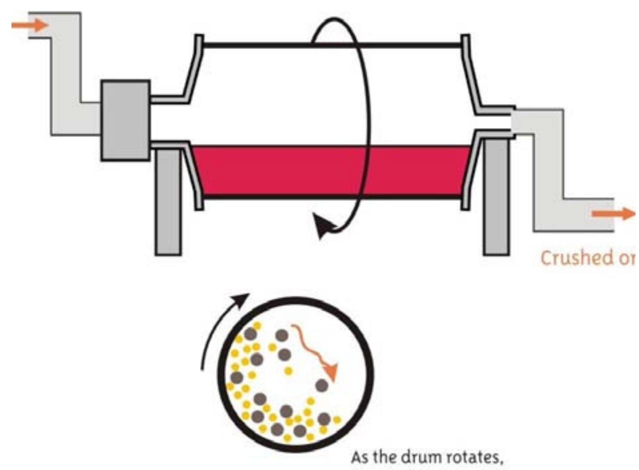
Crushing Stage 2 – Roll

The final crushing stage at Britannia used Roll Crushers (Traylor Rolls) (above). These consist of two rotating cylinders that draw the ore down between them. The ore is crushed as it passes through. At this point, the ore is now ready for grinding and was fed into six giant Fine Ore Bins. Roll mills were used in the Mill until 1956, when they were replaced by rod mills; roll mills were known as noisy, dusty and costly to run.

Grinding – Ball Mills

After being crushed and stored in the Fine Ore Bins, the ore began its grinding phase. The primary grinding method used at Britannia was Ball Mills, though by 1956 they were being replaced by Rod Mills . Roll Mills were also used at times too. Grinding took the ore down to the consistency of sand and was known as rock flour, or Fines.

Ball Mills are large steel drums, partly filled with steel balls; the fine ore is fed in one end and the ground ore is removed from the other.



The drum rotates, agitating and cascading the balls and ore. The cascading effect of the balls breaks the ore on impact, and the rolling nature grinds the ore as the balls and ore rubs against each other. The speed of rotation is calculated to be most efficient. Too slow and grinding will happen far too slowly, too fast and the rotation acts like a centrifuge and the balls will be held against the outside of the drum and not fall in. The drums at Britannia rotated at 20 to 24 rpm (report from 1932).

When the ore is fed into the ball mills, it is ¾ inches in diameter and has been mixed with 30% water to make a pulp. The water is essential for the froth flotation and must be added at the grinding stage (see Froth Flotation for more information). The flow of water through the mill helps the grinded material pass through from the inlet to the outlet pipes.

Because of the hardness of the Britannia ore, the steel balls used in the ball mills wore down quite quickly. Each Britannia ball mill contained 7 tons of 3½ inch balls and consumed 2½ lbs steel per ton of ore milled. So by 1924, rail slugs were being used instead of buying in steel balls. The slugs were not quite as efficient as balls, so a ball making machine was developed on site to turn rail slugs into rail balls. This was a key technical achievement in the Mill as it greatly cut down on milling costs.

When the balls reach a size of 1 ½ inches, they were replaced. But the smaller balls were then used in the regrind mills (see Froth Flotation – Summary). Another method used was lining the mills with 7 inch sections of scrap rail steel (cut by hot saw then quenched in cold water to harden), set end-on in high strength concrete. These linings lasted for 2 years and were replaced when they were about 2 – 3 inches thick. By 1970 they were using rubber linings in the mills.

Along side the ball mills were Classifiers. The purpose of these was to separate out the finest material from the oversize material. Screens and grizzlies could not be used as the ore was now in a pulp, i.e. an ore/water mixture. Britannia used drag (also known as rake) classifiers. These consisted of inclined troughs with suspended rakes that traversed the trough. The pulp was fed into the bottom of the trough and the oversize material settled to the bottom. The movement of the rakes dragged the material uphill, while the fine material overflowed with the water and was carried to the next part of the process. By the time the oversize material reached the top of the trough, much of the water had drained away and the material was fed back into the ball mills.

Two sets of ball mills were used in the Mill – primary and secondary. Two-stage grinding, with a classifier in between, meant that the finest material could be removed from the system sooner, whilst letting the oversize material be returned to the primary mill. The finest material would be passed to the secondary mill where smaller balls would reduce it further. By the time the ore left the ball mills, and were passed through the classifiers as fines, they were ready for froth flotation.

Grinding – Rod Mills

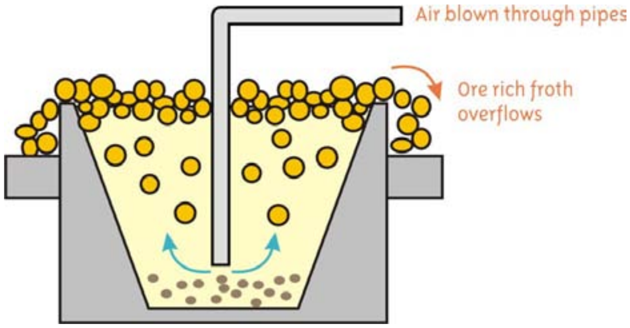
In the later years of the Mill (1950s), Rod Mills began to replace ball mills and roll mills. They worked on the same principle as ball mills, but instead of steel balls, long steel rods were used as the grinding media. The rods lay along the length of the drum and rolled as it rotated. Their rolling action was an efficient grinding process, meaning that the mills could rotate at a slower speed, which also cut down on the speed at which the steel wore down, i.e. both attributes saving money.

Another benefit of rod mills was that they reduced overgrinding. The larger pieces of ore tended to keep the rods apart, concentrating the grinding on the larger particles. The result was a granular ore, suitable for bulk flotation. This granular nature of the ore also meant that the discharge from the mill did not need to be passed over a classifier (see above), as the particles were a more even size.

Froth Flotation - Summary

Froth flotation was the key process in extracting the valuable minerals from the waste rock. The basic principal is to blow air through a mixture of ground ore/water/chemical reagents. The valuable minerals stick to the bubbles which rise to the surface to be collected.

When the ore is ready for froth flotation, it is a pulp, i.e. a mixture of ore, waste rock and water. This is fed into long troughs, called froth flotation tanks (or cells). The pulp was mixed with a chemical 'frothing agent' – at Britannia, steam-distilled pine oil was the favoured agent – and air was blown into the bottom of the cells, frothing it into bubbles. Another chemical reagent, known as a 'collector' was also added. This chemical acted as a waterproofing agent, chosen specifically for its properties to waterproof the ore minerals to be collected. When a mineral particle was waterproof, it stuck to a bubble as it rose to the surface. When the mineral-laden bubbles reached the surface they were skimmed off the top. The waste rock particles that hadn't been waterproofed stayed at the bottom of the tanks. They were said to have been 'depressed'. They could be removed and disposed of.



In a flotation tank, air is blown into the system to generate ore-laden froth

The process of 'bulk flotation' was pioneered at Britannia. In this, the first flotation was done to separate all the sulphide minerals from the waste rock. The collector agent used was generally potassium xanthate. This process left a 'concentrate' that contained a mixture of sulphide minerals (e.g. pyrite, chalcopyrite, sphalerite). The waste rock, known as 'tailings', were dumped in the Howe Sound, ultimately creating some of the land that is built upon today. It is estimated that 40 million tones of tailings were dumped offshore.

'Selective' or 'differential' flotation came after bulk flotation. Britannia was the first copper producer in North America to use selective flotation, increasing their recovery from 60% to over 90%. For selective flotation, the concentrate was reground in ball mills to produce a finer powder. Flotation was repeated but to 'depress' all the sulphide minerals with the exception of a particular metal sulphide. For example, pyrite and sphalerite were depressed in order to collect chalcopyrite.

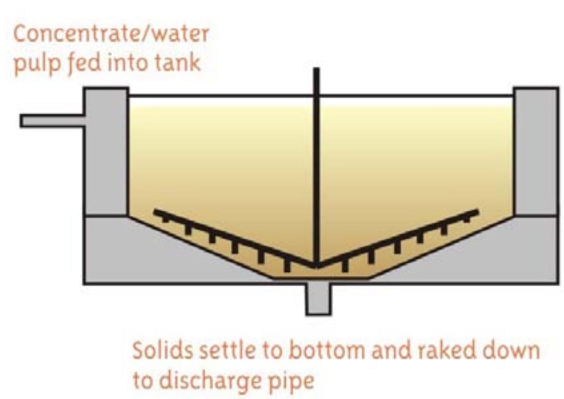
Lime was an important part of the froth flotation process, also. Lime depressed pyrite and was added at the regrinding stage (just before selective flotation).

There were different types of froth flotation machines on the market. Britannia used these but they also developed their own. Known as the 'Britannia Deep Cell' system, they were used for bulk flotation. Normally, flotation tanks were 2 – 3 feet deep, whereas the Britannia Deep Cells were 8 feet deep. These proved to be highly effective for the Britannia ore, leading to a recovery rate of 95%. However, it seems that although bulk flotation became a commonly used method elsewhere (and is still used in mining today), the Deep Cell system was unique to Mill No.3.

Dewatering

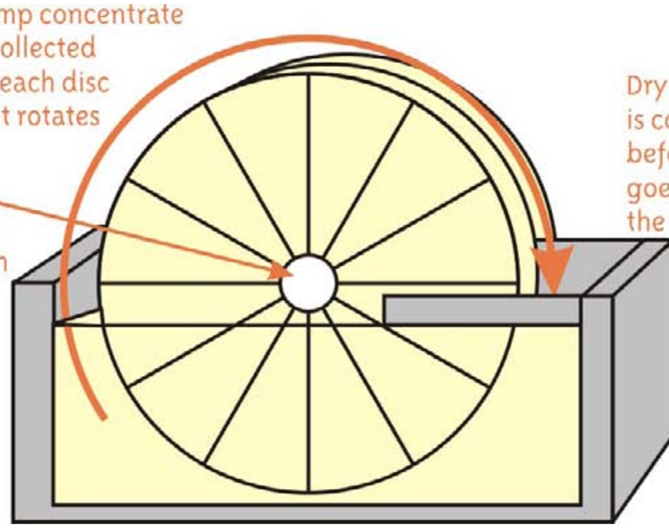
The final step in the Mill was to remove the water from the pulp – to leave the valuable ore that could then be shipped to the smelter. Removing as much water as possible had a number of benefits. It reduced the weight of the ore, reducing shipping costs, and also made the ore more stable in transit (dry products move/slosh around less than a slurry). It also allowed the chemicals and water that were used in flotation to be recycled back into the system. It is essentially a two–stage process – thickening and filtration. Thickening removes the majority of the water, and filtration using a vacuum pump removes additional moisture, producing a concentrate that is only about 10% water. It was then ready for shipping.

Thickening – At Britannia, dewatering happened in and around large tanks on the ground floor (now the three large wooden platforms). There were between two and five thickening tanks in the Mill, varying from year to year. Dorr Thickeners were the favoured tanks at Britannia. They consist of a large cylindrical tank, with a concave base. As the concentrate/water mix is fed into the tank, the solids settle by gravity to the bottom. A large rake/paddle rotates slowly, dragging the settled solids to a discharge pipe in the centre of the tank base. The weight of the overlying layer of solids naturally squeezes out most of the water from the solids near the rake at the base. A (diaphragm) pump removes the dewatered concentrate through the discharge pipe.



Filtration – There were two types of vacuum filtration, using either drum or disc filters. At Britannia, disc filters were favoured. These consisted of a series of circular discs mounted vertically on a heavy hollow shaft, mounted over a tank. Each disc was covered by a filter bag (e.g. of cotton), and was grooved to channel away the water as it was filtered. The discs rotate on the shaft, dipping into the thickened concentrate, then rotating into the air. Vacuum is applied through the hollow shaft, sucking the water through the filter bag and into the drainage channels. The resulting dry cake was left stuck to the filter bag until it was removed from the discs before they rotate fully back into the concentrate in the tank. The vacuum was created in the Roots Blower Shed outside the Mill.

Disc filters were the last stage of concentrate production, drying it before shipment to smelter



Mill Trivia

Production

Although designed to process 2000 – 2500 tons daily, by only 1924 it was determined that it could process up to 2800 tons daily. During World War II, and after many upgrades, production hit a high of 7200 tons daily; this was due to high copper prices. By 1952, production had dropped to around 3000 tons daily, when 5 grinding mills were taken out of service.

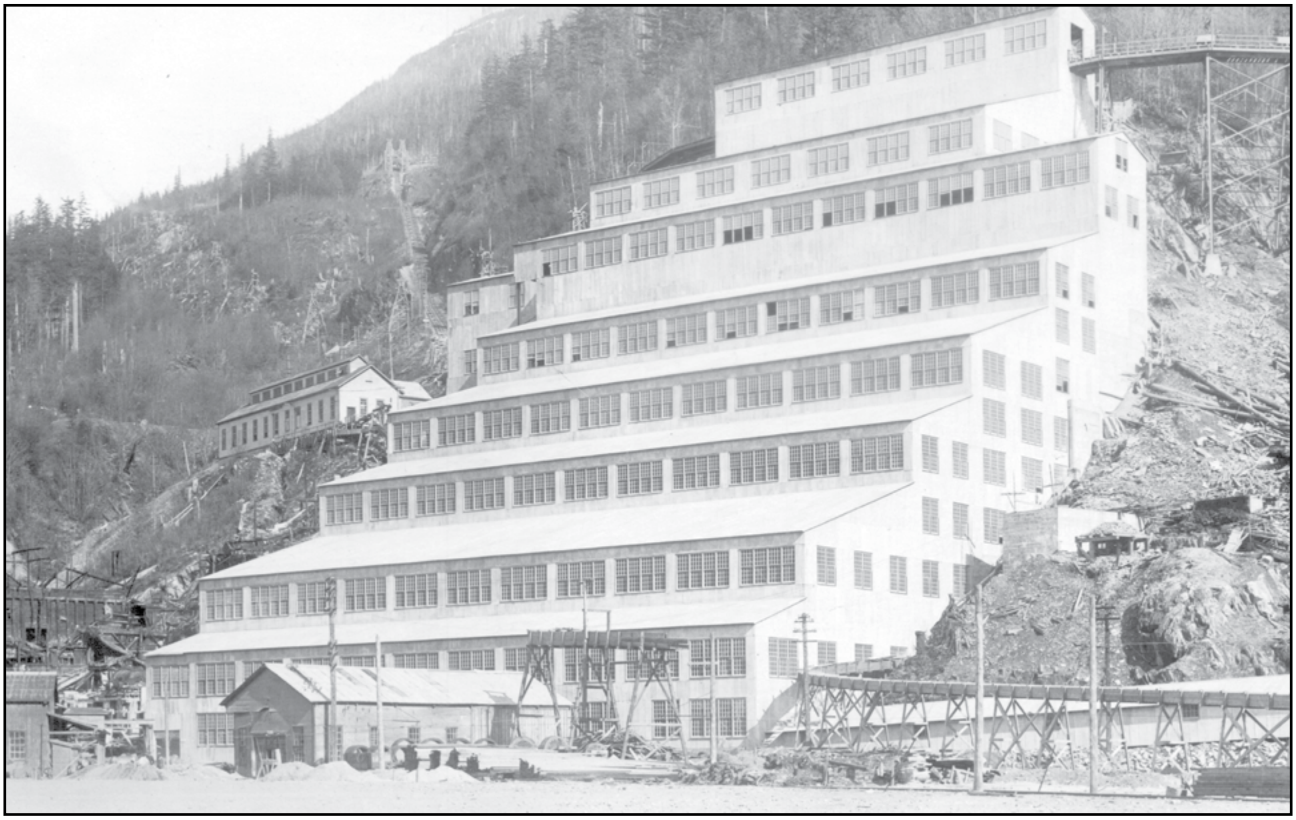
Technology

Manganese steel was used in the crushing and grinding equipment as manganese increased the steel's strength. This steel was manufactured on the site foundry

Tramp iron (i.e. stray iron objects from mining operations) that has been inadvertently incorporated with the ore, was removed from the Mill system by magnets

Experimentation

There was an almost continual process of experimentation to improve recovery rates and lower milling costs. There was a well equipped lab on site for technical analysis, including a small flotation machine and small rod or ball mill. Hundreds of tests were run to find better oils and reagents. A new mixture or product was never tried in the plant until it gave good results in the lab.



Mill Timeline – Key Dates

1905 - Mill 1 opens

1912 - First copper producer in North America to install a flotation unit as part of regular processing (Mineral Separation type)

1913 - First copper producer in Canada to use selective flotation

1916 - Power and water shortages meant Mill could not keep up with supply. Stockpile locations built above Mill site

1916 - Mill 2 fully operational

1919 - Mill 1 demolished

1921 - Mill 2 burnt down

1922/3 - Mill 3 built

1924 - Gold recovery begun in Mill 3 (though had been being extracted in earlier mill operations); Pyrite recovery begun (in May) in Mill 3 due to opening of market.

Rail slugs used for grinding; ball-making machine installed at Beach

1930 - Production reached a peak of 7100 tons per day, but averaging over 6000 tons per day over the year

1935 - Zinc production had begun

1936 - Britannia ranked as largest copper producer in world due to mining operation efficiencies (will have been contributed to by milling operations)

1938 - Production had declined during the Depression, but regained to around 6000 tons per day

1939/45 - During (but not necessarily throughout) World War II, production rose to record 7200 tons ore per day, due to high copper prices

1952 - Production reduced to 3000 tons per day (after several ball mills taken out of operation)

1956 - Rod mills were replacing ball mills and roll mills as they were more efficient

1958 - Primary crushing underground becomes cost prohibitive due to scale of mine; jaw crusher installed in Mill to process ore not crushed underground