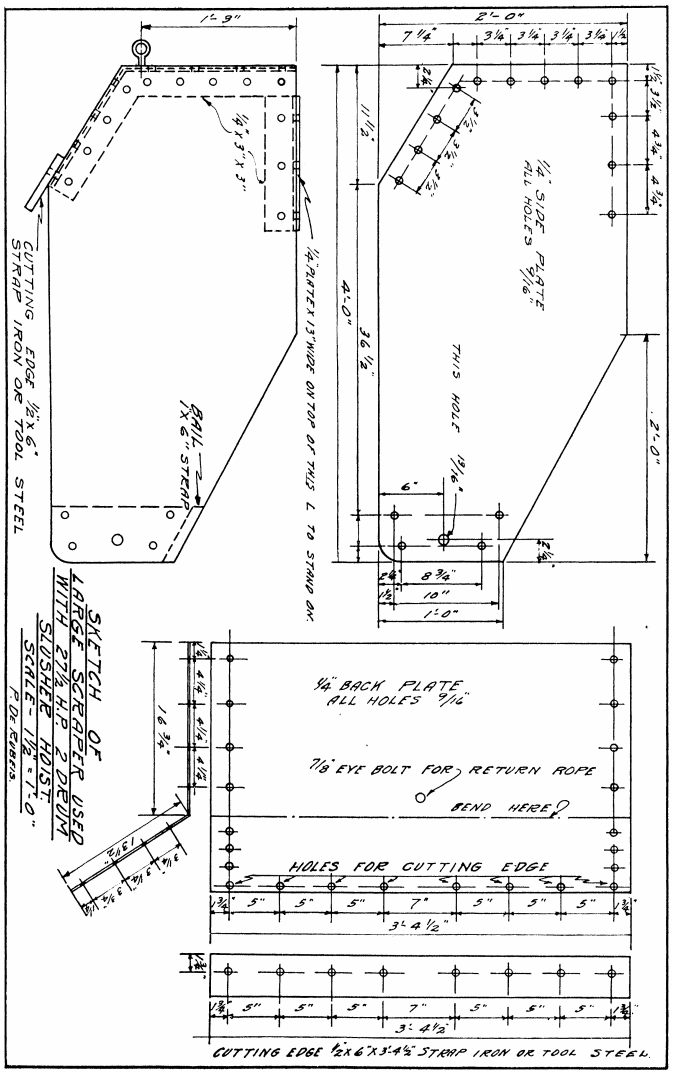
consists of only two men as the hoe will cut into rough ore so much better than the box type.

At a point 180 ft. above the 10½ level a transfer sub was driven west, split into three drifts where the dike was encountered. These drifts were under the orebodies shown in Sec. 1 and were extended into the dike a sufficient distance to allow a short storage raise to be put up to the ore. By the use of side boards, cars holding nearly 4 tons were provided for this transfer sub-level. Two of these cars were pulled by a 2½ ton electric locomotive. The chutes were provided with arc gates and all the work in connection with the tramming of the ore above the 180 ft. sub was handled by one man.

It was above the 180 ft. sub in the western end of the orebody that a rather definite mining practice was developed. Timber was placed above the storage raises and drifts driven on the dike to the limits of the ore. These drifts were not timbered. At intervals of 20 ft. raises were run up to the capping, either on the foot or hanging side of the drift. These raises were connected by a sub about 15 ft. below the capping". In connecting the raises a small electric -double-drum hoist was used and the ore slushed to the raise falling on the planked bottom of the drift below. The sub-drift was then widened to the rock walls, most of the ore falling down the raises. The back was then stoped to the rock capping and the capping very carefully trimmed. In other words the ore was cut off at the top.

While work was progressing on the sub-level the drift on the dike was being widened to the rock walls. The drift then resembled a drift-stope in the Copper Country, the dike taking the place of the foot wall. After the drift-stope was cleaned out stoping commenced on the back. If the back was of such height that a pillar still remained after a number of blasts and there was no working space between the broken ore and the back, the stope was cleaned out. Down holes were then drilled from the sub-level above as in suh-stoping. It sometimes happened that the back could be reached by going up on the dike and ore broken on which to stand to finish drilling the back pillar. A section of 60 ft. was stoped out clean at a time, working east from the west limits. At intervals old pieces of 1¼" hoisting rope were stretched across the stopej from foot to hanging to which, the snatchblock was attached. This made a very flexible arrangement and the snatch-block which hung from a rope clamp was moved as was necessary for scraping. Drilling machines were of four different types. In drifting auger machines or mounted water hammer machines are used. The mounted machines are used from a post and arm when drifting and were mounted on a tripod when stoping up on the dike with a high back. Auger machines mounted on a feed leg making a light self-rotating stoper using auger or ⅞" hex. steel are used in the good drilling ground for the back holes. Hand rotated stopers with ⅞" quarter-octagon steel are used for back holes in the hard ground.

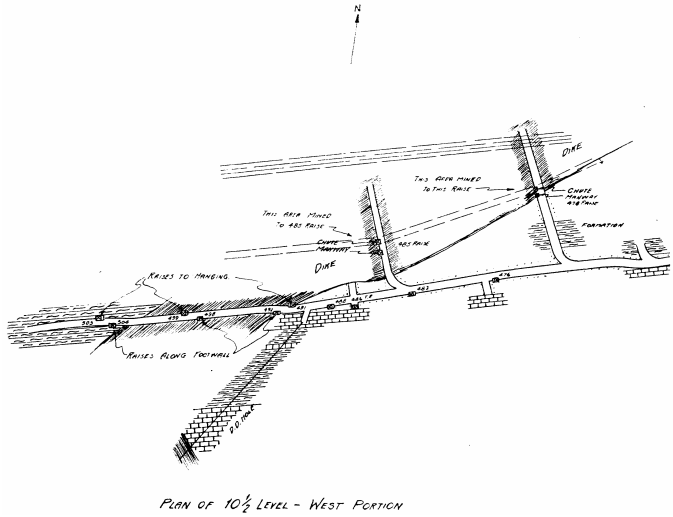


Where the capping did not come down to the dike but ore extended from the slate footwall to the hanging the same general method of mining was used. Arbitrary limits as to the width to be stoped were established, raises driven to the capping to determine the height of ore and location of the upper sub-level. Staging was occasionally used above the bottom sub, from which to drill, in which case blasting was always done electrically. It was never necessary to drive more than one sub above the one on the dike in order to mine all the ore between the dike and the capping.

Crosscuts were driven north from the main level drift to the hanging where raises to the north would not reach the ore. The crosscuts were 200 ft. apart. Raises from these crosscuts through the dike was the first step in a procedure similar to the operations in the territory above the 180-ft. sub except that there was no transfer, the ore being taken direct to the shaft. (See part plan of of 10½ level.)

From the earliest development of the orebody electric lights were used in the subs. The current was carried on well insulated lines and so-called "temporary" wiring was not tolerated. Extension cords 150 ft. long carried electric lights to the breast of drifts. In stoping flood

lights and extension cords with clusters of lights were used. The extension cords were of Tirex, a highly satisfactory insulated wire standing up well under the severe service of being dragged through the stopes.



NORTH PALMS MINE

It is difficult to determine the net result from well lighted working places. That proper lighting in a factory increases production per man and diminishes the loss from ruined material is an industrial axiom. With underground labor receiving nearly the equal in wages of the rate paid in the Ford automobile plant and the equipment they use often being many times more expensive than the justly famed Ford product it seems logical to illuminate the working place with something better than the ordinary carbide lamp.

With electric lights illuminating a breast where mounted machines requiring adjustment are in use it is noticeable that time is not lost in looking for wrenches and other tools. When a pile of broken ore is to be scraped and the pile well lighted the operator of the scraping hoist moves the scraper back and forth to pick up the load with very few signals from his partner. Neatness around any operation is probably the first step in safety work and it is quite easy to keep well lighted places neat as misplaced material looms up in a most noticeable fashion.

“Concrete Busters” for breaking chunks are part of the regular equipment with each 27½ h.p. scraper hoist. The raises into which these big outfits pull ore are 8x8 ft. at the top covered by a grizzly of rails spaced 14” apart. When a pile of chunks accumulates on the grizzly the hoist operator breaks them with the “Concrete Buster.” With the chunks well broken loading from the chute below is of course greatly facilitated. The “Concrete Buster” with moil weighs about 80 lbs. It is a non-rotating machine with the throttle in the handle. Hanging the machine by a spiral spring attached to a trolley running on a light circular strap iron rail above the raise takes the weight from the operator who works to greater advantage. The “Concrete Buster” under the conditions existing at North Palms is the equivalent of an extra man in the crew.

Power consumption for scraping with electric driven equipment is not high. A recording watt-hour meter was placed in the circuit with a Sullivan electric double drum hoist with a reading made at the end of a month. The machine was used in driving a drift so that the average distance the load was moved, was accurately determined1 by measurement. A record was kept of the tons of ore produced. There was a slope of 15 deg, in favor of the load. The power consumption was .17 k.w.h. per ton 100 ft. Power consumption was never recorded on the 27½ h.p. units but there is no reason to believe they are not equally efficient.

From January 1 to July 1, 1926, 73,208 tons of ore was mined from the North Palms working day shift only. Miners averaged 19.51 tons per shift. This includes all men drifting, crosscutting and raising to develop for stoping. In the six months’ period there was an average of 24.5 miners shifts per day. The boss, pipeman, electrician, chute crew, etc., added to the miners brings the rate down to 13.9 tons per man per shift for everybody underground connected with the operation.

The ore was trammed on the 10½ level an average distance of 2,230 ft. to the shaft. The tramming crew of four men—motor-man, two chute trammers who handle the stoppers and dump the cars at the shaft and chute poker averaged 165 cars per shift for the first six months of the year. The chute crew also brought all timber and powder from the shaft and hoisted it to the subs. Twelve cars make up a train. The cars are of the saddle back side dump type holding 2.9 tons.

The main level as well as the subs and stopes is well lighted. In fact it is not necessary to carry a lamp between the shaft and any working place. Power consumption for lighting, tramming and electric scraping averaged for the six months .83 k.w.h. per ton.

A writer on economics in discussing post-war conditions recently stated that, “Labor can be liquidated by other means than decreasing wages. Increasing the product per man accomplishes the same result with less economic disturbance.” The experience in the North Palms was that the careful application of known and tried equipment to certain conditions would increase the efficiency over old standards. The use of the “Concrete Buster” is a good illustration. The use of the hoe scraper under certain conditions is another. As with lighting, the saving in having a cage to handle men between the main level and 180 ft. sub is difficult to estimate. Traveling is so much easier that supervision is better, tools are delivered with greater dispatch and the miner spends more time at the working place.

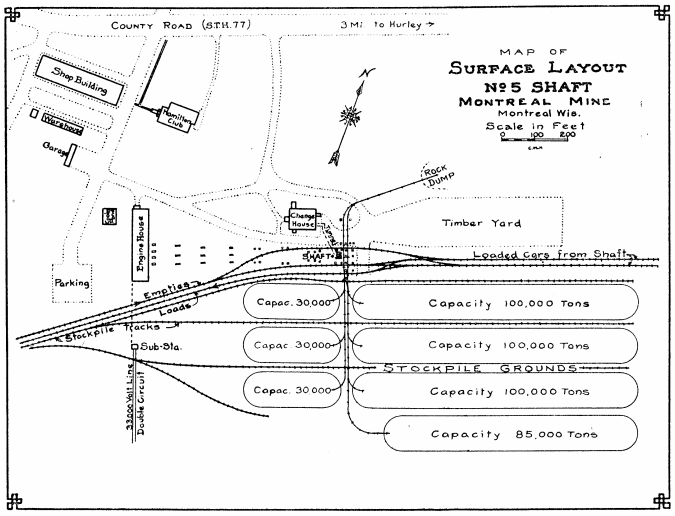
It seems that an improvement in working conditions, the lightening by machinery of the back-breaking end of mining should lengthen the active years of a miner and at good wages. In the long run this can have nothing but a good effect on the community.

THE MONTREAL MINING COMPANY'S NO. 5 SHAFT SURFACE LAYOUT.

BY L. E. DICK, MONTREAL, WIS.*

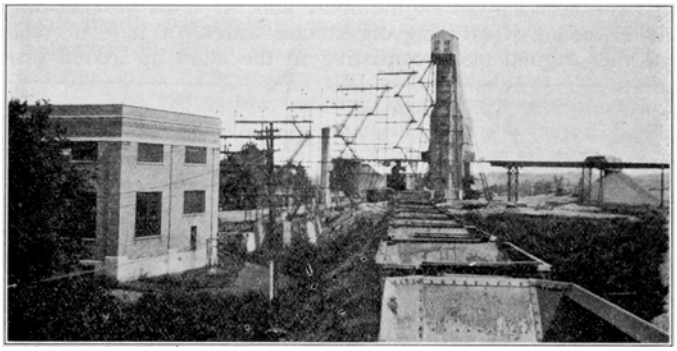
The surface layout of The Montreal Mining Company's No. 5 shaft was planned with the idea of having an absolutely fireproof and modern plant in every respect. The latest design of equipment was installed in order that efficiency and safety might be promoted. The whole No. 5 shaft territory is on an elevated piece of ground where the drainage is excellent. A gully running north and south between the engine house and the shaft provides an additional means of carrying off surface water. Where it could be done the original trees, consisting in the main of second, growth maples, were left in place. The accompanying plan map shows the dry or change house was placed close to the shaft, while the engine house was located 600 ft. west of the shaft in order to obtain a good fleet angle. The roadways are made of greenstone, hoisted and crushed at No. 5 shaft. On the northeast corner of the property the ground slopes downward very rapidly, and this feature was utilized by locating the waste rock dump at this place. The engine house, dry building, head frame and stocking trestles were all built by the Worden-Allen Company.

*Assistant Superintendent, Montreal Mining Co.



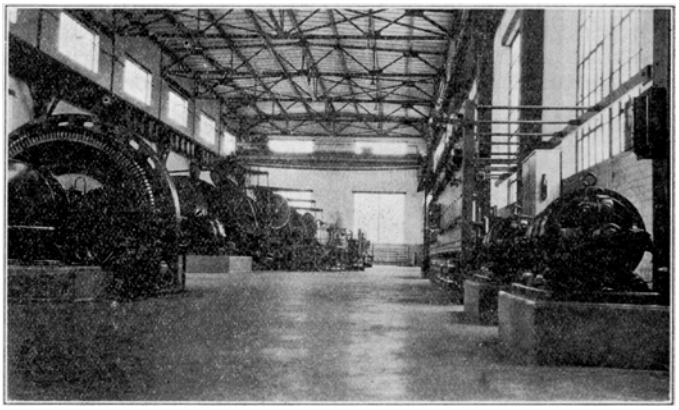
The electrical equipment is served by two independent power lines of 33,000 volts each, coming in to the transformer station south of the engine house. The transformers and high voltage lines are the property of the Lake Superior District Power Company.

From the transformers 23,000 volts is carried by duplicate submarine cables direct to the engine house. This building is 50 ft. wide by 213 ft. long by 53 ft. high, and consists of a steel framework with curtain walls of Chicago common brick laid up in chocolate colored cement mortar. The roof is of gypsum pyrobar slabs laid on tee rails and covered with Johns-Manville roofing. Steel doors and sash are used, the sash being glazed with factory hammered glass. Each lower sash is equipped with an individual mechanism for ventilation, and the upper sash is fitted with gang operators. The foundation walls are made of concrete with a concrete basement floor and steel beams and reinforced concrete main floor slab. A stairway leads to the basement from the main floor at each end of the building. The steel frame work supports a 40-ton single motor Pawling and Harnischfeger traveling crane in addition to the roof. There are 4,000 square feet of cast wall radiation installed on the main floor. Low pressure steam comes from the heating plant in the dry building 440 ft. away through a 6-in. main with a 2½-in. return. These outside lines are covered with wood stave insulation and are below the ground level.



SOUTH END OF ENGINE HOUSE WITH DRY, HEADFRAME AND TRESTLES IN BACKGROUND

The south end of the engine house contains the skip and cage hoists. These were built by the Nordberg Manufacturing Company and are driven by 600-hp. motors made by the Westinghouse Electric & Manufacturing Company. Both hoists are equipped with Lilly safety controls and the skip hoist is connected to a Johnson recording system. Each hoist is, at present, operated by magnetic control, with the contactors placed on separate panels in the basement. The installation of the gear drive on the skip hoist is so arranged that it can be removed very quickly and a first-motion motor installed should production increase sufficiently to warrant it. At present the hoists are practically duplicate installations. The leading dimensions are as follows:



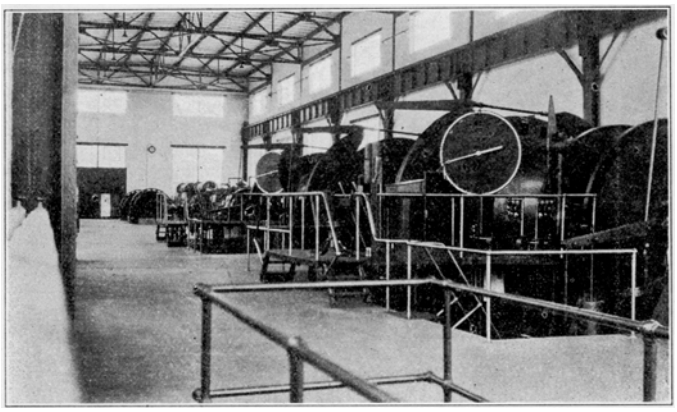
ENGINE HOUSE INTERIOR LOOKING SOUTH

Drums, 10 ft. diam. x 120-in. face grooved for 1⅜-in. rope.

Rope capacity, 4,500 ft. in two layers.
Brakes, 14-ft. diam. x 13-in. face.
Clutches, Axial friction type.
Center bearing, 18-in. diam. x 30-in. length.
End bearing, 17-in. diam. x 30-in. length.
Pinion bearings, 8½-in, diam. x 24-in. length.
Brake cylinders, 5-in. diam. x 24-in. stroke.
Clutch cylinders, 5-in. diam. x 24-in. stroke.
Gear, 207 teeth, 1½ D. P., 19-in. face, Falk-Herringbone.
Pinion, 19 teeth, 1½ D. P., 19-in. face, Falk-Herringbone.
Accumulator, 16-in. diam. x 48-in. stroke.
Francke flexible coupling.
WR^2 in balance, 4,000,000 lb. ft.^{2}
WR^2 out of balance, 2,400,000 lb. ft.^{2}

CONDITIONS OF SERVICE—
Weight of normal load, 9,000 lbs.
Occasional maximum load, 13,500 lbs.
Weight of cage, 9,500 lbs.
Size of rope, 1⅜-in. diam.
Maximum length of travel, 4,500 ft.
Rope speed, 1,000 ft. per min.
Shaft, vertical.
Acceleration period, 15 seconds.
Retardation period, 15 seconds.
Hoist to operate normally in balance except when changing levels or in emergency.

MOTORS—
Westinghouse induction motor, type CW, 600-hp., 2200-volt, 60-cycles, 3-phase, 155-amp. per terminal, 355 r.p.m. full load, 477 volts between slip rings at stand still, 551 amp. per ring at full load, 100 per cent load for 24 hours, 40 deg. C. rise, 125 per cent load for 2 rs., 55 deg. C. rise.

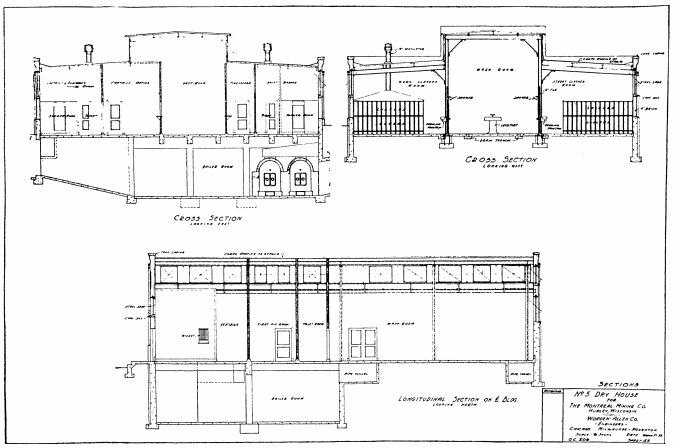


ENGINE HOUSE INTERIOR LOOKING NORTH

The engine house also contains two duplicate compressors built by the Ingersoll-Rand Company. Circulating water for cooling-purposes is supplied the compressors by two centrifugal pumps, drawing 20 gals, of water per minute from a cooling pond outside the building. The compressors are fitted with recording temperature gauges and low-water alarms. Each compressor has an after-cooler. A receiver, 300 ft. from the building and housed in an underground vault takes the air from the compressor. The leading dimensions of the compressors and driving motors are as follows:

Size, H. P. (right hand), 17½-in. x 21-in.
Size, L. P. (left hand), 28-in. x 21-in.
Direct connected to synchronous motor, type A. T. I. 40, made by General Electric Company.
K. V. A. 180, Form E, Cycle 60, Amp. 53.4.
Speed, 180 r.p.m.
Horsepower output, 450.
Capacity of compressor, 2,275 cu. ft.
Separately excited by 12.5 kilowatt motor-generator made by W. E. & M. Co.

In the engine house there is also a D. C. motor-generator set for tramming service, purchased from the Westinghouse Electric & Manufacturing Company. The motor is an induction motor, type C. S., 149-hp., 2200-volts, 36-amps., 3-phase, 60-cycles with a speed of 875 r.p.m. under full load. The generator is type S. K. compound wound, 100-kw., 275-volts, 365-amp. There is also floor space left for a large flywheel motor-generator set in case the hoisting demands require this type of installation.

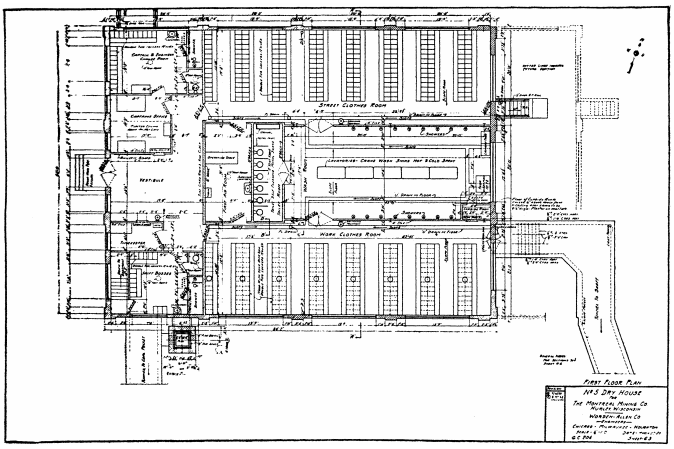


SECTIONS OF NO. 5 DRY HOUSE

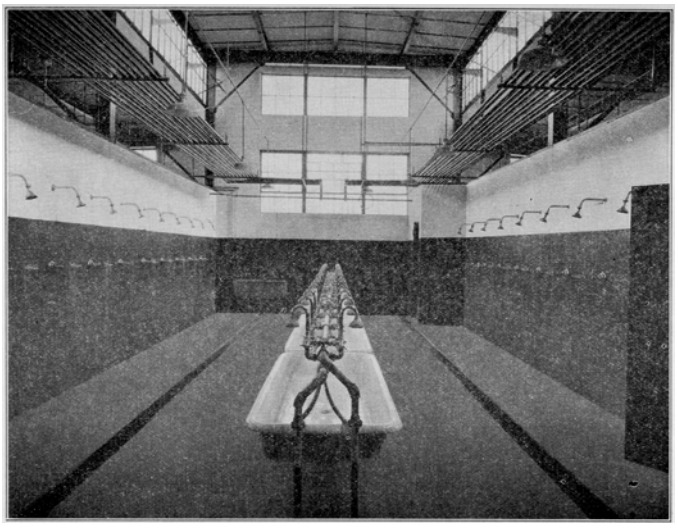
All the electrical equipment is controlled from an 18-panel switchboard located on the main floor. From this switchboard, elcetrically operated switches housed in concrete cells in the basement can be opened and closed. The board has a complete set of instruments and meters. The cell structure in the basement houses busbars, transformers, circuit breakers and switches, and all high voltage control. The current on the switchboard used for controlling the higher voltage equipment comes from a set of storage batteries also located in the basement. The batteries are kept charged from a small motor-generator set on the main floor.

There is installed in the engine house a 100-station automatic telephone switchboard which serves the entire property. An autocall system in connection with the telephones permits code calling. The system is also equipped with a watchman's signalling device so that by using outside phones the watchman can record his visits to the different parts of the property.

The 500-watt lamps suspended from each roof beam of the building by suitable fixtures furnish ample light to the engine house. Toilet and locker facilities are located in the basement.



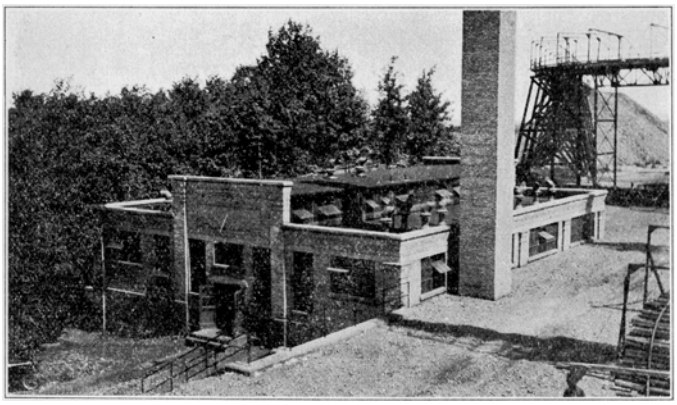
FIRST FLOOR PLAN—NO. 5 DRY HOUSE



INTERIOR OF NO. 5 DRY

The preliminary design of the dry building at No. 5 shaft was prepared by the engineers of The Montreal Mining Company. In connection with this design the following conditions were considered; sanitation, convenience, economy in operation and building, economy in heating, protection for the men going to and from the dry in cold weather and crossing the railroad tracks, ample space for captains, superintendents, engineers and visitors, eliminating' the fire hazard, enlarging the building without spoiling the effectiveness of the same, and also arranging so that the men can get through the dry with the least possible loss of time.

The dry building is 60 by 80 ft. and is of concrete, brick and steel construction with a pyrobar roof covered with fireproof roofing. The windows in the sides of the building are all above the tops of the lockers allowing good lighting during the daylight hours. The dry was designed to accommodate 450 men in addition to the captains and bosses. A man going to work enters the clean clothes locker room and removes his street clothes, then goes through the washroom to the mine clothes locker room where he has a second locker in the same relative position, with same number and using the same key. Here he puts on his mine clothes and then walks through the tunnel to the shaft. Under each bank of mine clothes lockers there is a steam coil, while over each one there is a hood leading to a ventilator. The interior divisions of the lockers are perforated to allow a free circulation of air.



NO. 5 DRY

The tunnel is on the same level as that of the main floor, and is built entirely of reinforced concrete; with the floor sloping towards the dry. The first-aid room in the dry is equipped with a surgeon's laboratory, surgeon's cupboard and massage table to be used in washing injured men, and also performing first-aid work. This room is well lighted and an operation could be carried on here if necessary.

The dry contains ample toilet facilities and on the inside walls of the wash room there are showers on both sides, together with the lavatories in the center of the room at which 30 men can wash at one time. All washroom drainage runs through open ditches covered with iron grating to a drain in the basement and from there to a settling basin of sufficient size to take care of any iron ore or any heavy material that might clog the sewers.

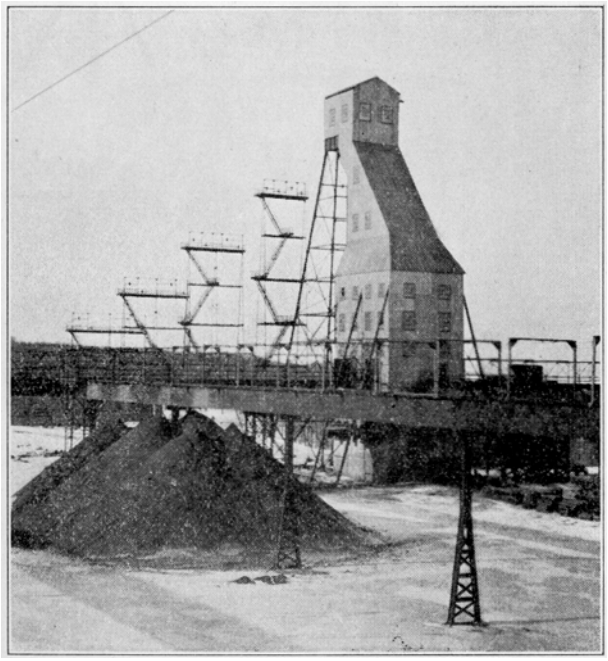
In the basement under the front part of the dry building there is a boiler room that serves to heat the engine house, the dry and the shaft house. The boilers are supplied with coal through a tunnel that runs out to a pocket under the railroad tracks where coal is dumped from hopper-bottomed cars. A large outside door facilitates the removal of ashes.

The basement also contains two 500-gal. tanks made of ½-in. steel plate, which are used for storing hot water. The main supply of hot water is heated in a small tank by means of steam coils connected with the large boilers. There is also an auxiliary stove heater which can be used in case the steam should be shut off. In connection with the hot water system there is a thermal regulator which keeps the water below the scalding temperature.

The dry is well lighted, large metal reflectors being used to distribute the light. All electric wiring is placed in conduit.

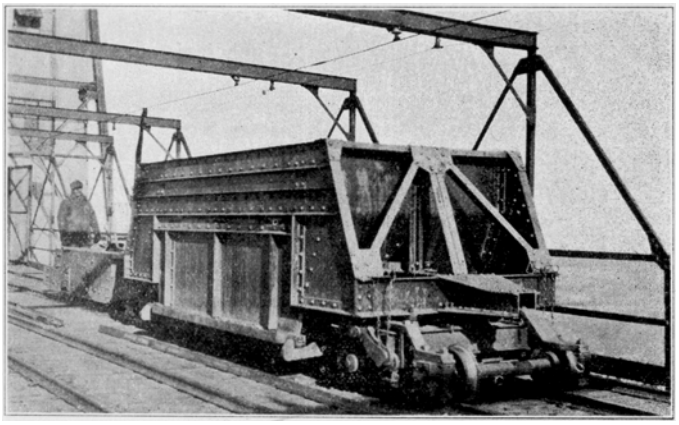
The head-frame over No. 5 shaft is built of structural steel covered with corrugated galvanized iron sheeting. The total height is 168 ft. and it contains 252 tons of steel. There are four loading pockets, two on each side

of the building, with a total working capacity of 300 tons of ore.



HEADFRAME VIEWED FROM STOCKPILE GROUNDS

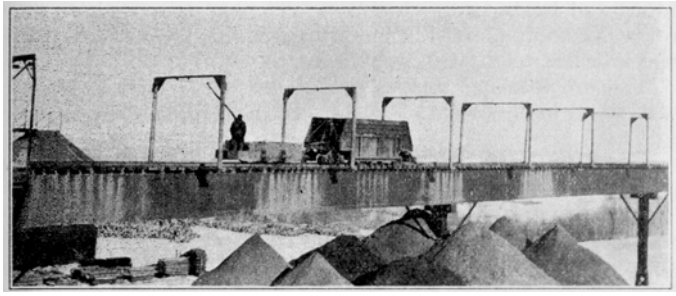
When a skip is dumped the ore passes over a grizzly placed at a 45-deg. angle with the horizontal. This grizzly is 16 ft. long and is made of two 8-ft. sections of 1 by 7-in. steel bars, each covered by a manganese steel cap or U-bar made by the Taylor-Wharton Company. The lower grizzly section can be raised by an air cylinder when it is desired to by-pass the ore or rock around the crusher.



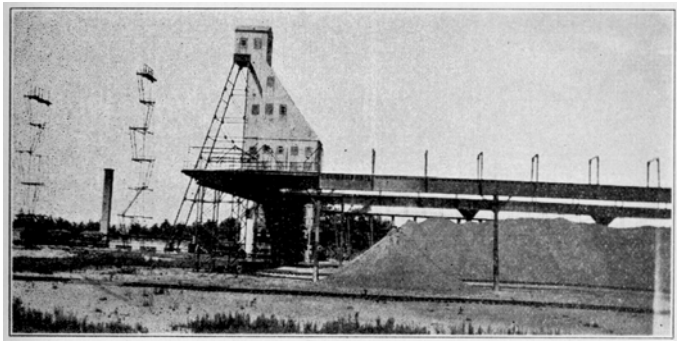
LANDING OR STOCKPILE CAR

A Telsmith No. 13 gyratory crusher reduces the oversize from the grizzly to a 2½-in. size. The crusher is belted to a 75-hp., 440-volt motor built by the Westinghouse Company. The product from the crusher drops on a picking belt where the rock is picked out by hand. The belt is 30 in. wide and moves at a speed of 75 ft. per minute. It is driven by a 5-hp. 220-volt induction motor through a gear reducer manufactured by Foote Bros. Gear & Machinery Company. The motor speed is reduced from 1,150 r.p.m. to 12 r.p.m.

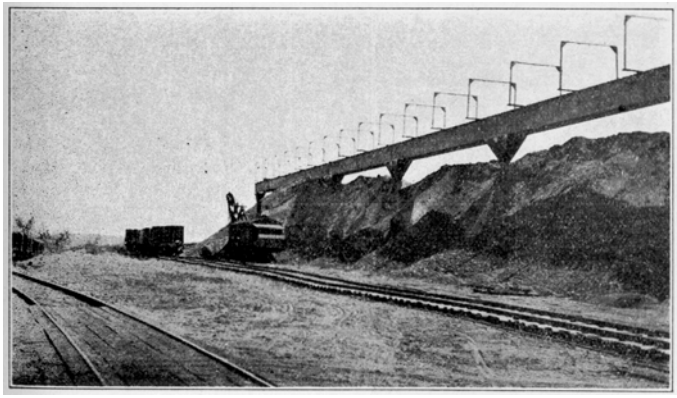
Through a system of steel chutes and deflectors the ore can be sent to any one of the four small pockets above the main landing floor. These pockets hold two skip loads and open directly to the landing car, or, during the shipping season, to the main storage pocket. The disc doors on the pockets above the landing floor are all air operated.



TRESTLE AND STOCKING CAR



IDLER STANDS, HEADFRAMES AND TRESTLES



LOADING FROM STOCKPILE

The landing car is a double-truck, 8-wheel, side-dump car built entirely of steel by the Lake Shore Engine Works. It weighs 8 tons and holds 14 tons of ore. The car is moved by a 4-ton trolley locomotive and the motorman dumps the car by pulling a rope attached to the tripping device.

The ore stocking trestles are of the single-leg self-supporting type, 38 ft. high, and are built of structural steel. The span from leg to leg is 66 ft.

Each of the five idler stands is self-supporting and is built of steel with a steel stairway leading to the top floor. There are 72 tons of structural steel in the idler stands.

In connection with the headframe there is a small auxiliary crushing and screening plant at No. 5 shaft used to prepare greenstone for concrete and also for road work around the mine.

The headframe, trestles, and idler stands were all designed by the Worden-Allen Company in conjunction with the Montreal Mining Company engineers, and built and erected by the Worden-Allen Company.

THE GOGEBIC RANGE MINES OF THE OLIVER IRON MINING COMPANY.

BY BYRON G. BEST, IRONWOOD, MICH.*

GENERAL.

The Oliver Iron Mining Company, a subsidiary of the United States Steel Corporation, operates fifteen properties on the Gogebic Iron Range, in Gogebic County, Michigan. As shown in Table I, these properties are divided into three groups: the Norrie-Aurora group in Ironwood, consisting of eight properties having an area of 640 acres; the Davis-Geneva-Puritan group, between Ironwood and Bessemer, of six properties having an area of 1,040 acres; and the Tilden mine, at Bessemer, of 320 acres. Fig. 1, a map of the central part of the range, shows the location of these and the adjoining properties.

*Mining Engineer, Oliver Iron Mining Co., Gogebic Range.

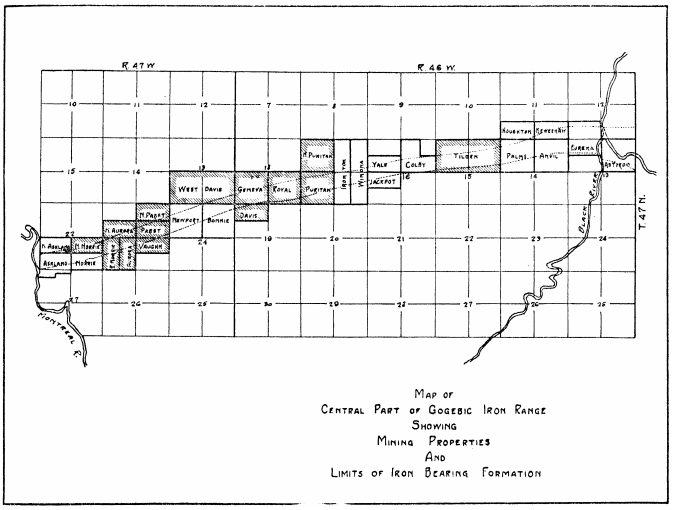


FIG. 1

The Norrie-Aurora and the Davis-Geneva-Puritan groups each consist of several adjoining properties and are divided into operating units, each of which is in charge of a mining captain.

In the Norrie-Aurora group there are four units:

1—The North Norrie, served by "A" shaft, and including the North Norrie and the North Ashland properties.

2—The East Norrie, served by "C" and "D" shafts, through which North Norrie and East Norrie ore is hoisted.

3—The Aurora, served by "E" and "F" shafts, hoisting Aurora, North Aurora, Vaughn, and Pabst ore.

4—The Pabst, with "G" and "H" shafts, and mining Pabst and North Pabst ore.

TABLE I.

GOGEBIC RANGE PROPETRIES OPERATED BY THE OLIVER MINING COMPANY.

Property and Group—	Description.	Area in Acres.
Norrie-Aurora Group—		
North Ashland	N½-SW¼-Sec. 22-T47N-R47W	80
North Norrie	N½-SE¼-Sec. 22-T47N-R47W	80
East Norrie	W½-SW¼ Sec. 23-T47N-R47W	80
Aurora	E½-SW¼-Sec. 23-T47N-R47W	80
North Aurora	S½-NW¼-Sec. 23-T47N-R47W	80
Vaughn	N½-SE¼-Sec. 23-T47N-R47W	80
Pabst	S½-NE¼-Sec. 23-T47N-R47W	80
North Pabst	N½-NE¼-Sec. 23-T47N-R47W	80
Totals for group		640
Davis-Geneva-Puritan Group—		
West Davis	S½- Sec. 13-T47N-R47W	320
Davis	N½-NW¼-Sec. 19-T47N-R46W	80
Geneva	SW¼- Sec. 18-T47N-R46W	160
Royal	SE¼- Sec. 18-T47N-R46W	160
Puritan	SW¼- Sec. 17-T47N-R46W	160
North Puritan	NW¼- Sec. 17-T47N-R46W	160
Totals for group		1,040
Tilden mine	N½- Sec. 15-T47N-R46W	320
Grand total—15 properties		2,000

The Davis-Geneva-Puritan group consists of three operating units:

1—The Davis, served by No. 1 Davis shaft, and hoisting Davis, West Davis, and Geneva ore.

2—The Geneva, with one inactive shaft and one which is now being sunk, from which will be mined Geneva, Royal, and possibly West Davis and Puritan ore.

3—The Puritan, served by No. 1 Puritan shaft, through which is hoisted Puritan, North Puritan and Royal ore.

The Tilden mine is served by one shaft, No. 10.

These properties are operated under leases which usually fix the royalty as a percentage of the selling price of the ore (at the lower lake ports) and specify the minimum royalty which must be paid each year,

GEOLOGY.

The geology of the district has been described in detail by Hotchkiss, Van Hise, Leith, and others.

Briefly, the iron bearing formation consists of a series of beds of ferruginous chert and ferruginous slate, lying on a quartzite footwall. In the central part of the district the thickness of the formation varies from 500 to 1,000 ft., averaging about 800 ft. The strike varies from N. 60 deg. E. to N. 85 deg. E., and the dip is approximately 65 deg. to the north. The formation is cut by numerous diorite and diabase dykes which dip to the south approximately at right angles with the formation. The dykes, quartzite, and ferruginous slate beds are impervious to water, and in the troughs formed by the

intersection of the dykes and the other two members downward percolating waters have formed orebodies of varying shapes and dimensions. Most of the ore is soft red hematite, although small quantities of hard blue "steel ore" are encountered.

Fig. 2 is a cross-section showing the geological structure of the range. This section is based on Hotchkiss' description of Gogebic Range geology, but differs in the classification of some of the members.

EARLY HISTORY AND MINING METHODS.

Actual exploration for iron ore on the Gogebic Range was started in 1880, but it was not until 1883 that a body of merchantable ore was discovered at the Colby mine, which for a number of years included what is now the Tilden property. The first shipment was made in October, 1884, when 1,022 tons of Colby ore were shipped on flat cars over the Milwaukee, Lake Shore, and Western Railroad (now part of the Chicago and Northwestern system). The ore was probably sent to Milwaukee and then to Erie.

Other discoveries were made in rapid succession and in 1885 the Norrie, Aurora, Vaughn, Pabst, Ashland, Germania, and Sunday Lake mines made shipments, followed in 1886 by the East Norrie, Puritan, and others.

In the fall of 1885 the Milwaukee, Lake Shore, and Western Railroad completed its line connecting the mines with Ashland, where the company had built the "largest single dock in the world." A second dock was completed in 1887, and in the same year the Wisconsin Central Railroad (now part of the Soo Line) completed its branch line from Mellen to Bessemer.

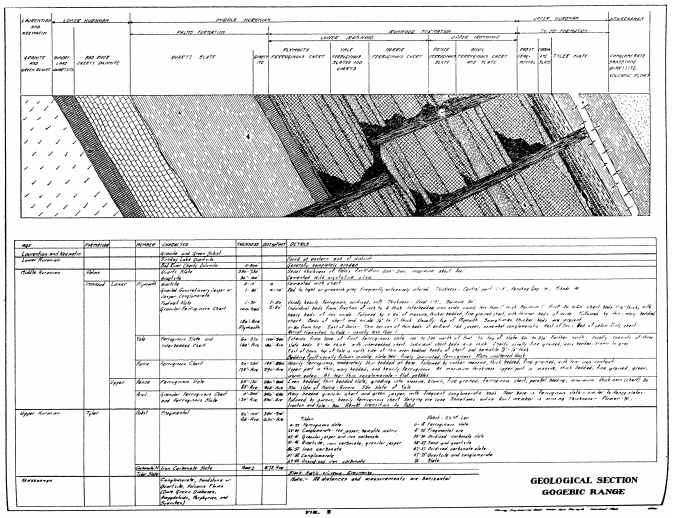


FIG. 2

Prior to 1880, J. M. Longyear, agent for the Lake Superior Ship Canal, Railway and Iron Company, had secured for his company, his associates, and himself a large amount of land in the iron bearing district. Options and leases were granted explorers who, if they discovered ore, formed companies to operate the properties. Since it was unusual for a company to operate more than one property a large number of mining companies were thus organized. As time passed, consolidations, failures, and other causes reduced the number of companies operating the properties now controlled by the Oliver Iron Mining Company to five: The Metropolitan Iron and Land Company, the Penokee and Gogebic Consolidated Mines, the Wisconsin Manganese Ore Company, the Corrigan-McKinney Company, and the Tilden Iron Mining Company.

Since the first ore discovered was close to surface it naturally followed that most of the early exploratory work was done by test-pitting, although in several instances diamond drills were used as early as 1887.

The Colby, Tilden, and Aurora mines were first operated as open pits, 350,000 tons being mined in this, manner at the Colby before any shaft sinking was started. However, open pits were the exception rather than the rule and at most properties it was necessary to sink shafts, sometimes through rock, before mining operations could be started. Since little was known regarding the size and extent of the orebodies, particularly as to depth, early shafts were sunk for exploratory as well as for mining purposes. On those properties where the orebody was continuous the distance between shafts varied from 150 to 500 ft., the average being about 300 ft. Shafts were small, usually consisting of two compartments—a skiproad and a ladderway—and were often the continuation of test pits. Most of the shafts were sunk on and followed the footwall, although there were a few vertical shafts sunk in the iron formation and others sunk vertically to the foot-wall and then inclined with the formation.

Probably the first permanent shaft was sunk at the Ironton mine, where in 1887 a shaft had been sunk in the quartzite footwall to the 3rd level at a depth of 170 feet.

In 1888 some of the "modern" shafts were No. 3 at the Iron King (Newport), with three compartments—skip, timber, and ladderways, and No. 5 Colby, which was 6 by 22 ft. inside of timbers, boasted of two skip compartments, and was located south of the footwall.

Early shafts were lined with timber and headframes were constructed of the same material.

An idea of early hoisting equipment may be gained from a statement made in 1887 that the Palms machinery consisted of two 70-h.p. boilers, two powerful 5-ft. hoisting drums, and two 4-ft. drums, together with the necessary pumps and appurtenances." There was also a "smaller hoisting plant used for exploring and other lighter work. Everything about the mine showed evidence of having been built with a view to permanency." In 1888, however, three 10-ft. drums had been installed at the Ashland and a somewhat similar installation planned for the Norrie.

Room and Pillar Mining.

Prior to 1898 nearly all of the underground mines on the range used the square-set room-and-pillar method of mining. Levels and half-levels were cut at intervals varying from 35 to 85 ft. vertically, the customary vertical distance between levels being 60 or 65 ft. Drifts from the shaft were driven near the foot wall or in the center of the orebody, and from these drifts square-set rooms were opened. Rooms and pillars were usually three sets wide, making the width of the rooms 24 ft. and the pillars 20 ft.

In opening a three-set room, ground for the center set was first removed and a crosscut started toward the foot or hanging. As the crosscut advanced the room was widened and the side sets placed. All posts were placed on mud-sills. After the first floor or tier had been timbered, a timber raise was put up to the level above, and the second and succeeding tiers opened from this raise. When this procedure was impossible, the upper tiers were opened and timbered in the same way as the first tier.

Whenever possible the room was cut and timbered to the level above, but in heavy ground it was often necessary to leave a floor pillar. When a room had reached the desired height, holes were bored in each post and cap in the upper tier. After the holes had been charged the fuses were tied together and the entire tier blasted at one time. The room was then cleaned out and the pillars mined by driving a center crosscut to the foot or hanging and removing the ore in tiers three sets square.

The miners drilled, blasted, and occasionally helped the timber-men. Except in rock work all drilling was done by hand. Timbermen brought timber from the shaft and placed it in the rooms, using block and tackle in the latter operation. Trammers loaded the ore into cars and trammed it to the shaft. Shaft pockets were not used, the ore being dumped directly from the cars into small skips—usually of one-ton capacity. At first the broken ore was allowed to fall to the floor of the room and the trammers shoveled it into cars. Later the ore was caught above the first tier and loaded into cars through chutes.

Production depended not upon the amount of ore broken by the miners, but upon the hoisting capacity of the shaft and the speed with which the trammers removed the broken ore from the rooms.

Semi-Permanent Shafts—1890.

\s the mines increased in size and depth, the limited hoisting capacity of the small shafts, the difficulty of keeping them in operation—due to the increasing weight of the ground—and the large amount of ore which was tied up in shaft pillars, made it advisable to abandon many of the original shafts and to sink shafts of greater hoisting capacity and more permanent nature. In 1890 sinking was started at the following shafts: "C" East Norrie (also known as "B" and the "Curry shaft"); "A" Aurora; No. 1 Aurora; "C" Pabst; No. 1 Geneva; No. 6 Tilden; and No. 9 Tilden. With the exception of No. 1 Aurora and No. 1 Geneva, which were sunk on or near the footwall, these were vertical shafts started in rock in the hanging part of the formation. All were lined with timber sets. Not only the shafts, but also the skips, hoisting equipment, and headframes were increased in size. Even though the shafts were sunk in the formation and some of them struck the footwall at depth, that they were of a semi-permanent nature is evidenced by the fact that with the exception of No. 9 Tilden, which was destroyed by fire, they were all in operation in 1918. The steel headframe at "A" Aurora was the first structure of this kind on the range.

Introduction of Sub-Level Caving.

With changing mining conditions the disadvantages of the room-and-pillar method of mining became more apparent and pronounced with the result that in 1898 sub-level caving was introduced in the Oliver mines.

At this time machine drills were seldom used except in shaft sinking and rock work, hand drills and jumpers being used in nearly all other work. Hand augers were used occasionally, but they were difficult to obtain, and once secured were jealously guarded. The No. 3 Rand was the standard machine drill, and only on rare occasions were machines of this type found in the sub-level workings.

Cribbing was cut in 4 and 8-ft. lengths. Joggles were framed at the ends, but none were cut in the center of the 8-ft. pieces. The ladder road was separated from the ore compartment by planks held in place by cleats nailed to the 8-ft. cribbing.

For some time after the introduction of sub-level caving all ore broken on the subs was trammed to the raises in wheelbarrows, which were soon replaced by half-ton cars, or "buggies."

It was at this time, 1898, that electric locomotives were first introduced underground and that shaft pockets came into general use. Ore was hoisted in skips of one- to three-ton capacity, or in main level cars which were run on the cages. In several shafts the skips were suspended beneath the cages.

Shaft Data
Gogebic Range Properties
Oliver Iron Mining Company

Mine	Shaft	Steady Dimensions	Shaft Angle	Shaft Bulkhead	Cut Floors	Pockets	Stations	Lath	Shaft Bulkhead	Skip Pockets	Skip Chute	Skip Capacity	Skip Speed	Skip Shaft Size	Hoist Location	Geological Location	Hoisting Speed	Hoisting Rope	Production 1890-1918	Headframe	Headframe Dimensions Above Collar	Size of Sheaves	Rope Diameter	Rope Length	Cage Diameter	Cage Length	Cage Dimensions Over Posts
Aurora	A	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3" Plank	6'-0"	3'-0"	3'-0"	1'-7"	4	7.0	Hancock & South Range	South Side	1000	1 3/4	1,148,000	Steel	17'-0"	10'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
E. Norrie	C	6'-0" x 12'-0"	5°	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	Ironwood	South Side	1100	1 3/4	1,145,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
E. Norrie	B	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	Ironwood	South Side	1100	1 3/4	3,000,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Aurora	E	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	South Side	South Side	1100	1 3/4	2,400,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Aurora	F	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3" Plank Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	South Side	South Side	1100	1 3/4	1,145,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Pabst	G	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0" 3'-0" x 3'-0"	3" Plank 3" Plank Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	Ironwood	South Side	1100	1 3/4	2,148,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Pabst	H	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	Concrete	5'-0"	—	—	1'-7"	4	6.0	Ironwood	South Side Gogebic	1100	1 3/4	900,000	Steel	17'-0" x 17'-0" 8'-0" x 8'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Geneva	No. 1	6'-0" x 12'-0"	5°	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3" Plank Concrete	5'-0"	3'-0"	3'-0"	1'-7"	4	6.0	Ironwood	South Side Gogebic	1100	1 3/4	400,000	Steel	17'-0"	9'-0" x 12'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Geneva	No. 1	6'-0" x 8'-0"	5°	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	3" Plank	5'-0"	3'-0"	—	—	1	1.0	Gogebic	Gogebic	400	3/8	30,000	Timber	8'-0"	8'-0"		300 ft.	4'-0" x 8'-0"	5'-0"	
Geneva	No. 6	6'-0" x 12'-0"	6	4'-0"	4'-0"	4'-0"	4'-0" x 3'-0" x 3'-0"	Concrete	5'-0"	—	—	1'-7"	2	1.0	Ironwood	Gogebic	1000			Steel	17'-0"	9'-0"	1 1/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0"
Aurora	No. 1	6'-0" x 12'-0" 3'-0" x 3'-0"	4	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3'-0" x 3'-0" 3'-0" x 3'-0"	3" Plank Concrete	5'-0" 3'-0"	3'-0"	3'-0"	1'-7"	2	1.0	South Side	South Side	1100	1 3/4	2,400,000	Steel	17'-0"	10'-0"	7/8"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0" Only one hoist. Cage and skip interchangeable
Tilden	No. 6	6'-0" x 12'-0" 3'-0" x 3'-0"	5	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	3'-0" x 3'-0"	3" Plank	5'-0"	—	—	1'-7"	2	1.0	Ironwood	Gogebic Range	1000	3/8	1,000	Steel	17'-0"	10'-0"	1/2"	1,170 ft.	5'-6" x 2'-0"	6'-0"	5'-6" x 2'-0" Only one hoist. Skips hung below cages

TABLE II

PERMANENT SHAFTS—1900 TO DATE.

The year 1900 marked another important advance—that of sinking permanent shafts in rock south of the footwall. The first Oliver shaft of this kind was “A” Norrie, on which work was started December 11, 1900. The shaft was started in quartz slate about 75 feet south of the face of the footwall. It was inclined at 58 deg. with the horizontal. The shaft was 6 by 22 ft. inside of timbers, and was divided into live compartments—two skip roads, a cage road, a counterweight compartment, and a ladder and pipe compartment. It was lined with light steel sets and plank lath.

During the next ten years minor changes were made in shaft design and construction. Rails, channels, tees, and small I-beams and H-sections were all used. In 1912, when sinking was started at “C” East Norrie, H-beams were adopted as the steel section most suitable for use in shaft sets. “C” shaft was lined with steel sets and precast concrete lath, and was the first fireproof shaft to be sunk by the Oliver Iron Mining Company on the Gogebic Range. It was sunk in quartz slate, inclined at 64 deg., and contained five compartments.

“E” Aurora, started in 1916 and similar to “C” East Norrie, was the last inclined shaft sunk by the company in this district.

The first vertical shaft south of the footwall was “H” Pabst, which was started in 1917. The upper part of the shaft is in quartz slate and the lower part in granite. “H” was also the first Oliver shaft to be located with the longer dimension at right angles to the strike of the formation. The shaft is divided into five compartments. The counterweight for the cage is a piece of shafting which travels through a 10-in. pipe. Figs. 3 and 4 show the steel set and concrete lath used in the upper part of the shaft. In that part of the shaft which was sunk through granite the sets were made of 6-in. H-beams.

Data relating to the various shafts of the company are given in Table II.

GENEVA SHAFT.

Due to the possibility of movement along the contact of the quartz slate and the granite, the Geneva shaft was started in granite, about 25 ft. south of the contact. This shaft, at which sinking is now in progress, is rectangular, 10 ft. by 23 ft. 6 in. inside of timbers, and is divided into six compartments—two cage compartments 5 ft. 10 in. by 10 ft.; two skip roads 5 ft. 2 in. by 6 ft. 4 in.; one ladder compartment and one pipe compartment, each 3 ft. 4 in. by 5 ft. 2 in. The end pieces, wall plates, and dividers are 4 in. H-beams, and the cross dividers 4 in. H-beams. Sets are spaced 6 ft. center to center. The shaft is lined with 3 in. precast concrete lath, held in place by angles riveted to the webs of the H-sections. The plan of the shaft is shown in Fig. 5.

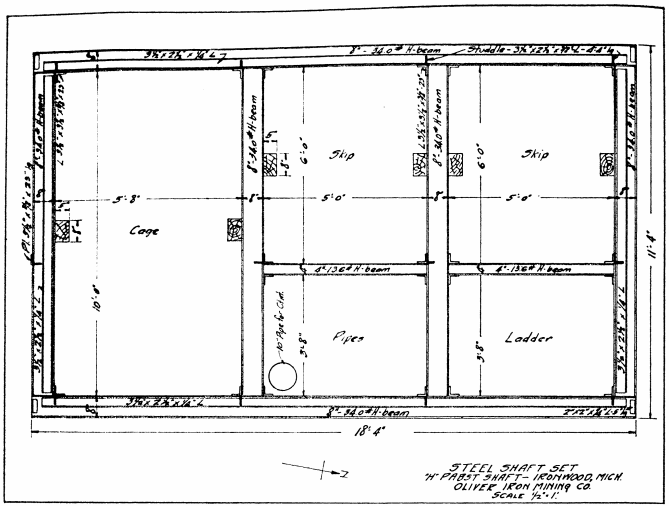


FIG. 3

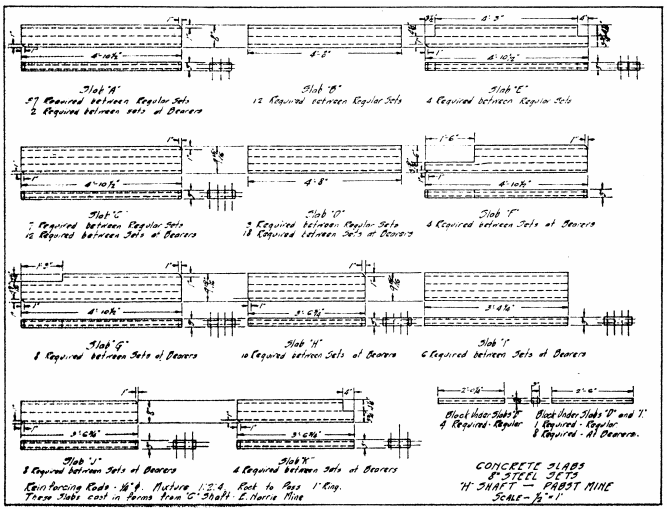


FIG. 4

It is planned to sink the shaft to an ultimate depth of 4,000 ft., with the first opening from the shaft at a depth of 2,845 ft. Permanent equipment will include a steel headframe, steel idler stands, concrete-block engine and compressor house, all of which have been erected, a fireproof change house, and possible permanent stocking trestles.

The steel headframe, 36 by 42 ft. at the base, is located on the south side of the shaft, as will be most of the permanent equipment. The center-line of the sheaves is 92 ft. above the collar, and the top of the structure 108 ft. 6 in. above the collar. Bicycle sheaves 12 ft. in diameter are used.

The permanent hoist and compressor house is a concrete-block structure, 40 by 142 ft. on a masonry foundation. This building is located about 530 ft. south of the shaft and will house the following equipment:

(a) One ore hoist—single-drum, 12 ft diameter by 17 ft. 6 in. face, grooved for 1¾-in. rope, with single-reduction herringbone gears, driven by a 1,500-h.p. induction motor, and designed to operate two 10-ton skips in

balance from an ultimate depth of 4,000 ft. at a maximum speed of 1,500 ft., per minute.

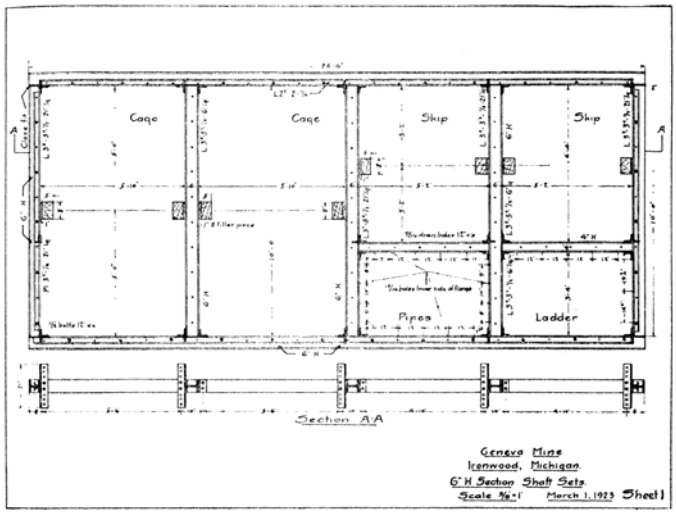


FIG. 5

(b) One cage hoist—single-drum, 12 ft. diameter by 13 ft. 6-in. face, grooved for 1⅜-in. rope, with single-reduction herringbone gears, driven by a 500-h.p. induction motor, and designed to operate two double-deck cages, in balance, from an ultimate depth of 4,000 ft. at a maximum speed of 1,000 ft. per minute.

(c) Two 2,300-cu. ft. motor-driven air compressors.

(d) Transformer sub-station equipment.

Power for the hoists, compressors, haulage, and other purposes will be generated by a 4,000-k.w. turbo-generator installed at the central power plant at "G" Pabst. The 22,000 volt transmission line from the Pabst to the Geneva is carried on steel towers.

Work preliminary to actual shaft sinking was started in July, 1922. The permanent loading track was laid as far as the shaft, and later a temporary track was extended to the permanent engine house for use in the installation of machinery. A temporary engine and compressor house, a frame structure 31 by 59 ft. inside, was built about 135 ft. north of the shaft, so as not to interfere with the installation of permanent equipment. This building houses the following equipment.

(a) Two double-drum hoists—48 in. diameter by 36 in. face, driven by two 150-h.p. induction motors. Drums were grooved for 1¾-in. rope. Until the shaft had reached a depth of 2,154 ft. these hoists were used exclusively, one operating two sinking buckets in the two west, or cage compartments, and the other a bucket in the west skip compartment and a small cage in the east skip compartment.

(b) One 16-in. and 10-in. by 14-in.—600-cu. ft. air compressor driven by a 100-h.p. induction motor.

(c) One 14-in. by 12-in.—487-cu. ft. air compressor driven by a 100-h.p. induction motor.

As long as possible the Davis air compressor will supply air for shaft sinking, the compressors in the temporary engine house being for use in emergencies or in case the Davis supply becomes inadequate.

In connection with the temporary engine and compressor house is an outdoor substation enclosing three 150-k.v.a.—22,000—400-volt transformers and three 22,000-volt lightning arresters. A temporary power line from the Pabst-Puritan line supplies power for the temporary equipment. About 50 ft. north of the substation is a temporary cooling tower.

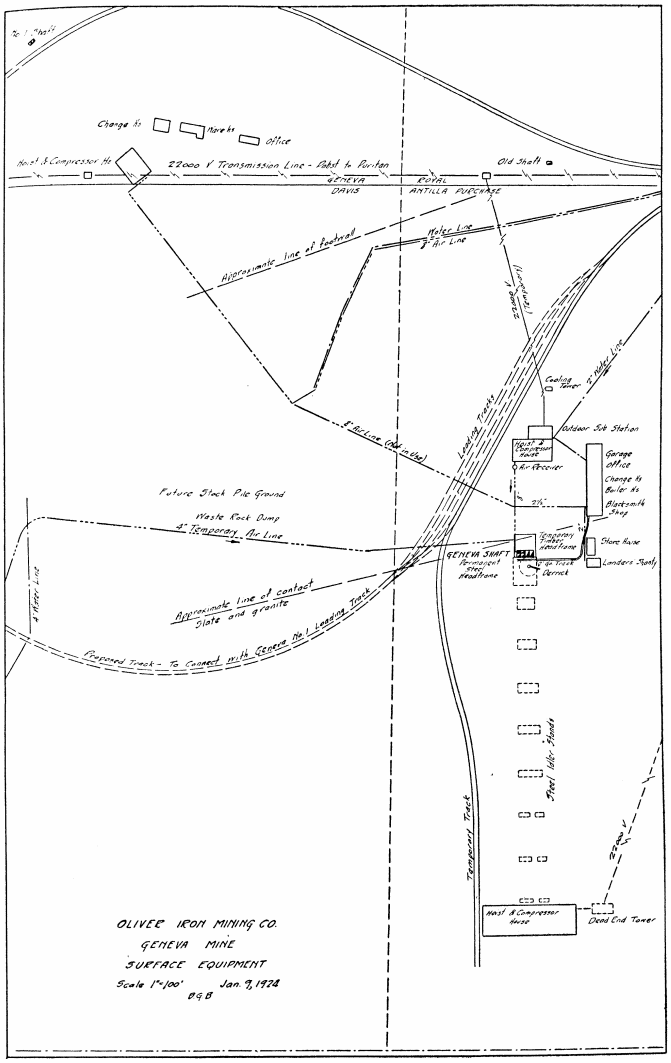


FIG. 6

At the shaft site only a few feet of surface material covered the granite, and to prevent damage by blasting to the temporary headframe the shaft was sunk 17 ft. before the head frame was erected. This sinking was done in October, 1922, and work on the headframe commenced the following month.

To interfere as little as possible with the erection of permanent equipment, the temporary headframe was erected over and north of the shaft. The headframe was built largely of 12 by 12-in. fir. It was provided with a rock slide, air-operated trap doors which covered the shaft while buckets were being dumped, and trap doors

at the collar which fit around the buckets and prevented anything from falling down the shaft when tools or supplies were being loaded.

Rock was dumped from the buckets over the slide into a 77-cu. ft. larry car, operated by a 20-h.p., alternating current, 900-r.p.m. motor. The car is of the remote control, worm gear type, and runs on a 36-in. gage track laid on a trestle west of the shaft. The waste rock is used to build up the stockpile ground.

Northeast of the shaft is a combination garage, office, change house, boiler house (for heating purposes), and blacksmith shop. In addition to other equipment the shop contains two oil burning drill forges and a drill sharpener. A 24-in. gage track runs from the shop to the shaft.

A lander's shanty and a storehouse were erected east of the shaft, and south of the shaft, in line with the divider between the cage compartment, was a derrick for handling steel and concrete lath. The location of the sinking equipment is shown in Fig 6.

Drilling equipment consists of fifteen sinking machines using 1-in. hollow hexagon steel. Ten machines are used at one time in the shaft, the other five being kept in reserve on surface. Drill steel is cut in ten lengths—2, 3, 4, 5, 6, 7, 8, 9, 10, and 12 ft. The 3, 4, 6, 8, 10, and 12-ft. lengths are used more than the others. The 2, 5, and 7-ft. lengths are used occasionally, and the 9-ft. steel rarely. The larger men will neglect the 2-ft. starters and the 5 and 7-ft. changes, while the smaller men find it necessary to use these lengths.

After considerable experimenting the cut shown in Fig. 7 was adopted as standard. A cut consists of 64 holes—four relievers, from 4 to 5 ft. deep in the center of the shaft and 12 rows of 5 holes each from 9 to 11 ft. deep. The cut holes are started about 5 ft. east and west of the center line of the shaft and are so pointed and inclined that the bottoms of the holes are from one to two feet apart. The second, third, fourth, and fifth rows also incline toward the center of the shaft, but at angles approaching the vertical. The sixth, or outside rows are vertical. A cut is drilled in from ten to sixteen hours and 350 to 400 drills are used per cut. Although the cut is broken in two blasts, all holes are drilled before any blasting is done, and wooden plugs driven in the holes to be fired in the second blast.

The first blast includes the relieving holes, two rows of cut holes, and the five remaining rows at the west end of the shaft. The relievers are fired simultaneously, but all other holes separately, working from the center of the shaft toward the outside.

Holes are charged with 1 by 8-in. 80 per cent gelatine-dynamite, about 350 lb. being required per cut. In charging a hole two sticks of powder are placed in the bottom, followed by the exploder, after which the hole is filled to within 15 or 18 in. of the top. No. 8 caps are used, with electric delay igniters which vary in length by ¼-in. When the holes have been charged they are tamped with water. Holes are fired by a current of no volts, carried from the surface lighting circuit to the bottom of the shaft by No. 12 wire. Two switches are used, a safety switch in the shaft and a blasting switch on surface. Both are enclosed in locked boxes and both must be thrown before the blast can be fired.

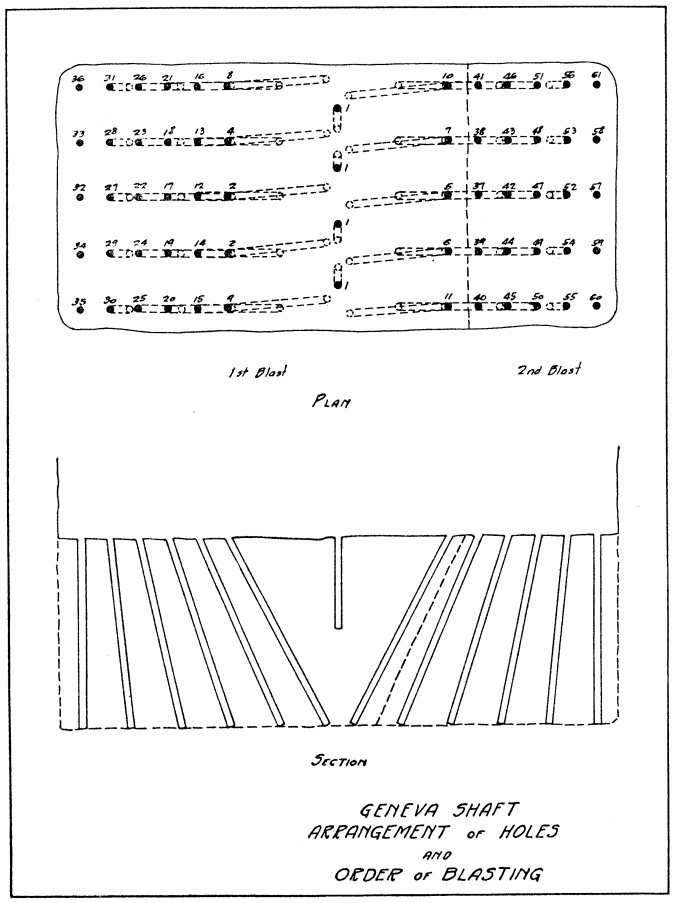


FIG. 7

In sinking the first 2,154 ft. of the shaft the broken rock was hoisted in three buckets varying in capacity from 21 to 29 cu. ft. The two buckets in the center compartments were used much more than the one in the end compartment.

Usually two or three shaft sets are placed at one time, this work being done on the day shift. The wall plates are lowered under the cage, using a 1-ton chain block with a 40-ft. chain. All other steel is lowered in buckets. The sets are placed and bolted by the miners, who work on staging made of tamarack plank laid on 30-lb. rails, which are hung from the shaft sets by ⅝ by 2½-in. strap iron stirrups about 2½ ft. long. The manner of hanging staging is shown in Fig. 8. In the installation of shaft steel the miners first hang their staging, after which they place the corner stuttles, wall plates, and end pieces in the order named. Temporary blocking is placed at the corners of the set, which is now wedged into line and securely blocked at the corners. The dividers and sub-dividers are now placed and the set permanently blocked with pieces of tamarack not less than 8 in. in diameter. Final blocking is done with cement in the following manner: One-in. boards about 3 ft. long are

nailed to the bottom of the blocking at the corners of the set and extend to the corners of the excavation, forming L-shaped boxes. Cement is mixed on surface and lowered in sacks, each being from ⅔ to ¾ full. Two sacks are placed in the boxes at each corner of the shaft, tamped, and allowed to set.

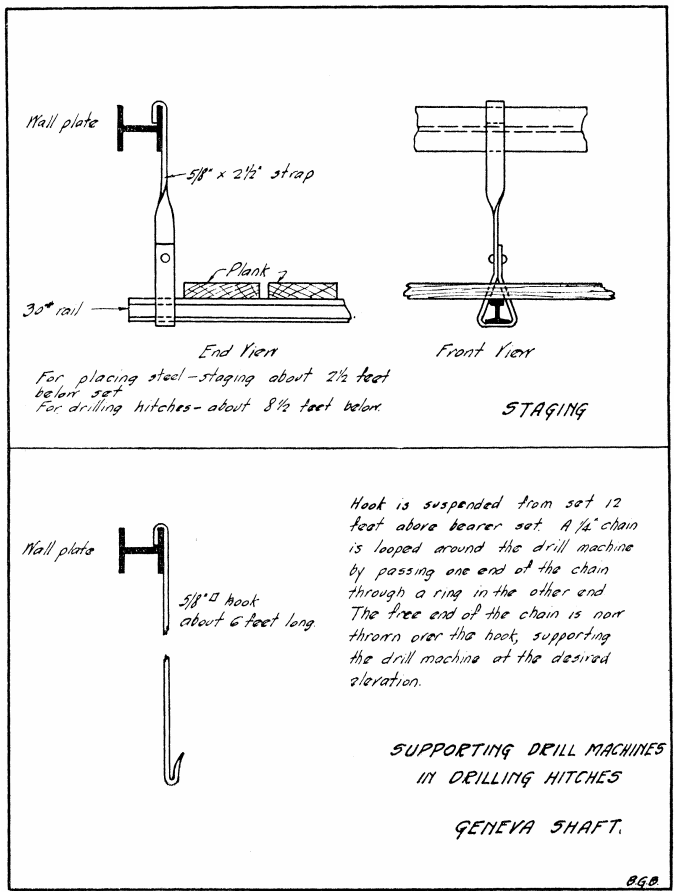


FIG. 8

After the sets have been blocked, lath are placed and the space behind the lath filled with cedar lagging. Concrete lath are lowered on the cage, and blocking and lagging in the buckets. Working on planks laid on the shaft steel, the miners place the lath, beginning at the corners of the different compartments and working toward the center. Two by 2½-in. angles, riveted to the webs of the shaft steel, form with the outside flanges of the shaft steel channels in which the lath are placed. Since the distance between the angle irons is less than the length of the ordinary lath, the first lath are inserted diagonally and brought to an upright position. When the open space in the center of the panel reaches 30 in. the lath can no longer be placed in this manner. A filler piece, 1¾ by 2⅛ by 30¼-in. is placed on the lower set, and lath 2 in. shorter than the regular lath placed as follows: The upper end of the lath is inserted behind the angle of the upper set and the lath lifted until the lower end will clear the angle of the lower set so that the lath can be dropped into place on the filler piece, which prevents the upper end from dropping below the edge of the angle on the upper set.

In drilling hitches for bearers, which are placed from 100 to 150 ft. apart, sinking machines are used to drill as many holes as possible in the rock to be removed. For this work the machines are suspended from the shaft steel by hooks and chains, or mounted on light tripods placed on staging. The hook for supporting machines is shown in Fig. 8. Bearer sets consist of five 12-in. I-beams, spliced in the middle to facilitate installation. The bearers are held securely in place by iron blocking and thin iron wedges.

Ventilation is secured by a 30-h.p. fan, which forces air down the shaft through a 12-in. pipe.

The shaft is comparatively dry, the amount of water handled being rarely more than three buckets in 24 hours. Most of the water comes from near surface.

In the summer of 1925, when the shaft had reached a depth of 2,154 ft, sinking operations were suspended while the temporary head frame was removed and the permanent steel structure erected. The exterior work on the permanent engine- and compressor-house had been completed by this time so that it was possible to install the permanent cage-hoist while the headframe was being erected. A 5-ton skip was installed in the east cage road to hoist rock from a transfer station cut at a depth of 2,057 ft. Arrangements were made to keep the temporary hoists in operation, one for a cage in the west skip compartment and a bucket in the other skip compartment, and the other hoist to operate a bucket in the west cage road and to move shaft steel from the storage pile to the collar of the shaft. At the transfer station a 40-ft. pentice was built to form a temporary skip-pit and to protect the miners, and trap-door slides built in the bucket compartments. Rock is hoisted from the bottom of the shaft in buckets and dumped into a pocket having a capacity of 30 buckets or 10 skips, but which is seldom filled to more than two-thirds its capacity. At surface the rock is clumped from the skip over a slide to the larry car, the capacity of the skip and car being about the same. The cage runs from surface to the bottom of the shaft, as do the buckets, which in addition to hoisting rock to the transfer station, are also used for hoisting and lowering tools and lowering small pieces of shaft steel, blocking, and lagging.

It is planned to continue sinking as described and without interruption until the shaft is deep enough to cut out the 30th level.

PRESENT MINING METHODS.

At the present time the sub-level caving method of mining is used in all the Gogebic Range mines of the Oliver Iron Mining Company.

Shafts are sunk south of the footwall, the present tendency being toward vertical shafts sunk entirely in granite. The average distance between the shafts of the Norrie-Aurora group—all but one of which are inclined shafts—is about 1,000 ft. Whenever possible, both for

safety and for ventilation, underground workings are connected with two shafts.

Main levels are opened from the shafts at vertical intervals varying from 85 to no ft., depending upon the following factors:

1—The size and shape of the orebody.

2—The distance from the shaft to the orebody.

3—The mining method to be employed.

4—The length of time that main level drifts can be kept open without excessive repair cost, which may depend partially or entirely upon the nature of the ground.

5—The life of raises, which may depend upon the nature of the ground.

6—The distance that the ore can be dropped through a raise without packing.

7—The number of sub-levels desired, and the distance between sub-levels, which depends to a large extent upon the other factors as well as the nature of the ground.

In opening a main level, a crosscut is driven from the shaft to the orebody and continued such a distance as may be necessary to mine the ore above the level or for exploratory purposes, which may entail some rock work. Fifteen or 20 ft. from the footwall (so that irregularities of the footwall will not make it necessary to change the direction of the drift) a drift is driven from the crosscut to the mining limit. If the orebody is of sufficient width parallel drifts are driven, the distance between drifts depending upon the following factors:

1—The width of the orebody.

2—The mining method to be employed. If the ore is to be mined by the regular sub-level caving method, the broken ore being loaded into cars by hand shoveling, the distance between drifts should be a multiple of the distance, center to center, between the drift-slices on the sub-levels.

3—The length of tram on the sub-levels.

4—The amount of repair work on sub-levels, which in heavy ground will increase as the distance between main level drifts increases.

5—The cost of main level drifting and raising, which increases as the distance between main level drifts decreases.

6—The amount of repairing on main levels, which increases as the distance between drifts decreases.

Except in rock, all main level drifts are timbered, using 8 ft. posts and caps and 6 ft. lagging. Sets are spaced 5 to 6 ft. apart, center to center. At regular intervals along the drift, depending upon the mining method to be employed, raise sets are placed. In its simplest form a raise set consists of three regular drift sets spaced 4 ft. apart, center to center, so that the cribbing of the raise can be laid on the caps of the drift timber. Raises are usually so located that those from the different drifts are in line east and west as well as north and south, thus blocking out the ore in a systematic manner.

Raises are 4 by 8 ft. outside of timber, and are lined with cribbing 4 ft. long and 3 ft. between joggles. Raises have two compartments, an ore chute and a ladder road, each 3 ft. square and each timbered independently of the other. In this way the two compartments are separated by two thicknesses of cribbing, and should the cribbing in the ore compartment become worn, it can he replaced without retimbering the ladder road.

It has been learned by experience that ore runs best in raises inclined at 65 deg. In flatter raises the ore hangs up, and in steeper raises it packs at the bottom. Raises are usually inclined to follow the formation, but in some cases it is necessary to incline them in the opposite direction, and in the case of a V-shaped ore-body it may be desirable to incline raises from the same drift in both directions, which is done by starting all raises from the same side of the main level drift and branching or turning them at the first sub-level.

Under ordinary conditions sub-levels, or subs, are opened from the raises at vertical intervals of 18 ft., which interval is considered to give the height of back most adaptable to efficient mining and high extraction. The first sub is 20 ft. above the main level, because the greater size of the main level drifts, the settlement of ground during mining operations, and repair work on the main level all tend to reduce the height of back between the main level and the first sub.

The number of subs to be opened at one time and the extent to which each sub is opened before mining operations are commenced depends upon the nature of the ground and the mining method to be employed. Subs are usually opened by driving a drift connecting a line of raises with a timber raise to the level above. Sub-level drifts are lined with 7 ft. posts and caps and 6 ft. lagging.

SUB-LEVEL CAVING.

I. *Hand Shoveling—Caving from One Side of Slice*.—When the ore is to be mined by the simplest form of sub-level caving main level drifts are usually driven at 60-ft. intervals and raises spaced 33 ft. apart, as shown in Fig. 9.

Mining is commenced on the top sub at one of the raises farthest from the shaft, which under ordinary conditions would be the farthest east or west raise from the hanging drift. A crosscut is driven from the raise to the hanging limit of the orebody. Starting near the end of the crosscut so that a pillar of ore, about 5 ft. wide, will be left on the hanging side, a drift-slice is driven to the east or west limit of the ore. When the east or west limit has been reached, the lagging on the hanging side of the last set is removed and the ore thus exposed between the slice and the hanging limit is blasted out. The miners shovel the broken ore into 1-ton cars and tram it to the

raise. The next step consists of removing the ore remaining between the slice and the hanging and above the opening made by the first cut. This usually requires two blasts. The final step in the caving cycle is the removal of the ore over the last set of the slice, which also requires two blasts. These steps are shown in the upper drawing of Fig. 10. Caving is now started from the next set, and the process repeated, one set at a time, until the crosscut is reached. A second slice is then started, 15 ft. (center to center) south of the first slice, leaving a pillar from 5 to 8 ft. wide between the two slices. The ore in the pillar and above the slice is mined as was the ore tributary to the first slice. This process is repeated until the entire block has been mined.

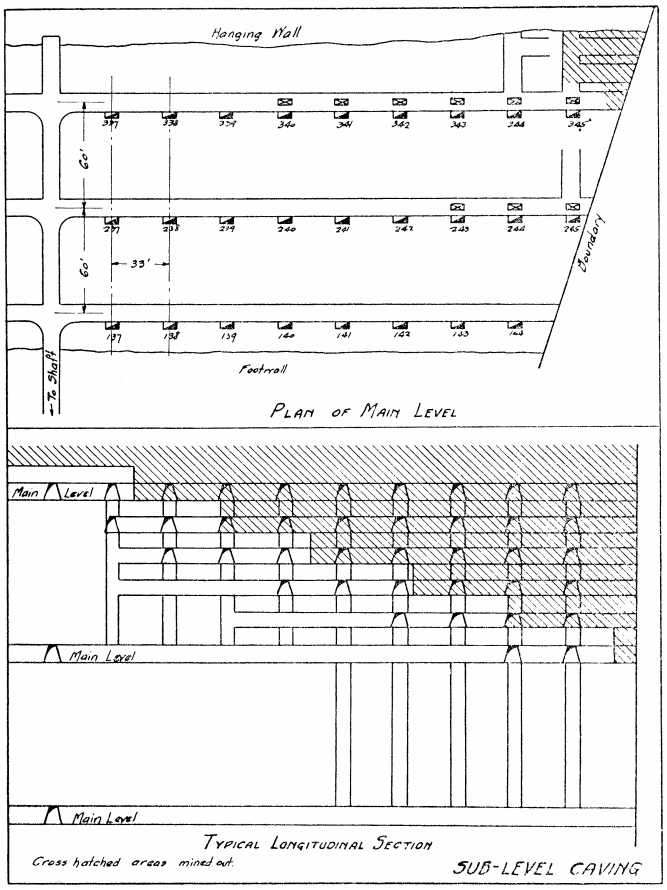


FIG. 9

Mining can now be started on the block east or west of the first block, and the block immediately below. The block east or west will be 33 ft. wide—the east and west distance between raises. The block to the south will be 65 ft. north and south—the distance between main level drifts. All regular blocks will be 33 by 65 ft. While mining operations are not usually started in a block until the block to the north and the block immediately above have been completely mined, it is customary to work several blocks adjacent to each other in an east and west direction at the same time, those blocks nearest the mining limit being in the more advanced stages.

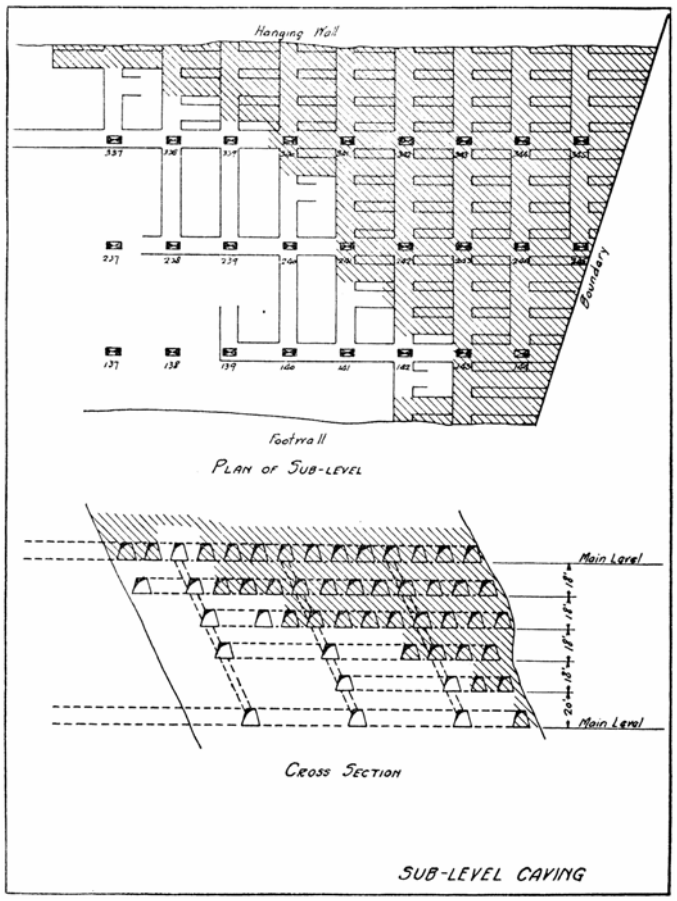


FIG. 10

After the ore has been removed the capping caves and mixes with the timber, forming a protective mat or gob which follows downward as mining progresses.

The manner of caving the slices as used at some of the mines differs slightly from the method as described. After the set nearest the mining limit has been caved, the next set is left intact and caving started from the third set, leaving a pillar of ore between the two caves. This pillar serves to hold back the gob until caving has reached the advanced stage, when it is mined in the ordinary manner.

II. *Hand Shoveling—Caving from Both Sides of Slice*.—In some of the mines the ground is sufficiently firm to allow caving from both sides of slice. When this method is used main level drifts are usually spaced 60 or 80 ft. apart. The raise interval is 33 ft. Subs are opened in the same manner as described above. Slices are 20 ft. apart. The lower drawing of Fig 11 shows the manner of removing the ore at each set. The pillar to the hanging is caved first, followed by a similar pillar on die foot side of the set, and the ore above the set caved last. Where this method can be used it results in a reduced drifting and timber cost, since the ore mined from each slice is increased 33 per cent.

III. *Hand Shoveling—Slicing from Both Sides of Crosscuts*.—A third method, which can be used in ground which stands well, is to increase the distance

between raises and to drive slices and mine from both sides of the sub-level crosscuts.

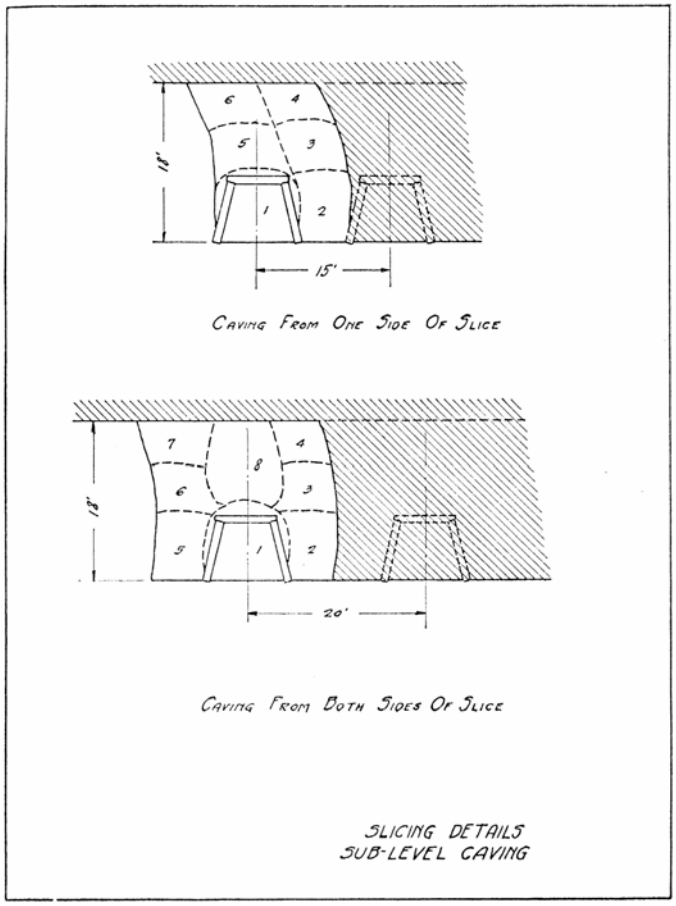


FIG. 11

IV. *Gravity Systems*.—To eliminate hand shoveling as much as possible on the sub-levels, gravity systems have been introduced and are used at some of the mines. These systems or methods are particularly adapted to fairly hard and firm ore which stands well and does not require a great amount of timbering.

Main levels are opened in practically the same manner as described for regular sub-level caving, except that drifts and raises may be spaced farther apart. In Fig. 12 the raises are 40 and 80 ft. apart. Thirty-five or 40 ft. below the top of the ore a transfer or tramming sub is opened by driving a drift connecting a line of raises. At 40-ft. intervals along this drift crosscuts are driven to the foot and hanging, and from both sides of these crosscuts single compartment raises (dog-holes) are put up to the sub above, or mining sub. Raises are staggered, and one is started from each set, making the distance between raises on each side of the drift 10 or 12 ft. On the mining sub, crosscuts are driven over each line of raises, most of the broken ore being blasted directly into the raises. In retreating, a pillar 5 to 8 ft. wide is mined from each side of the crosscut, and as before most of the ore is blasted into the dog-holes.

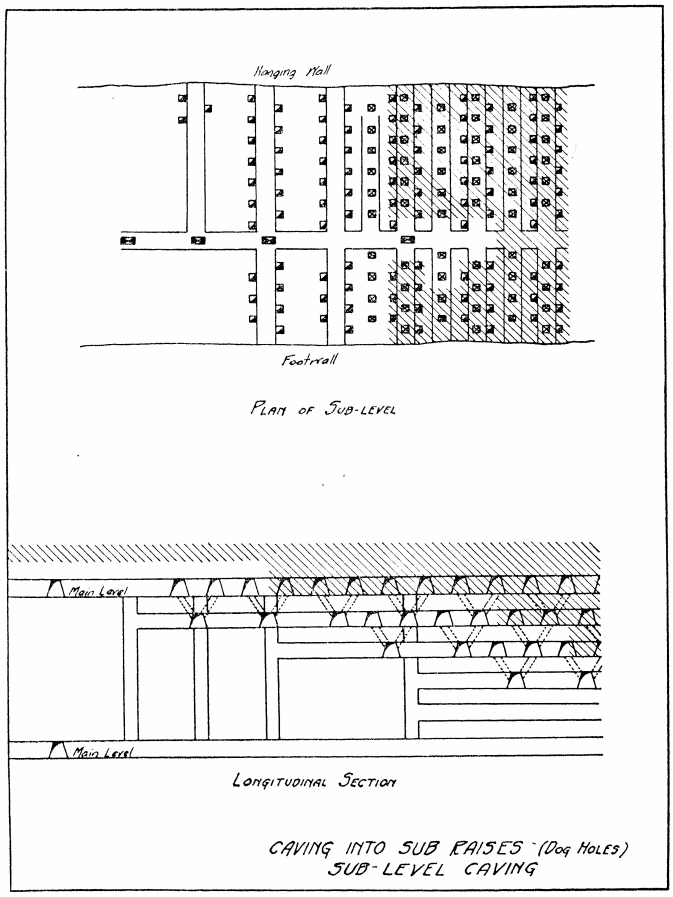


FIG. 12

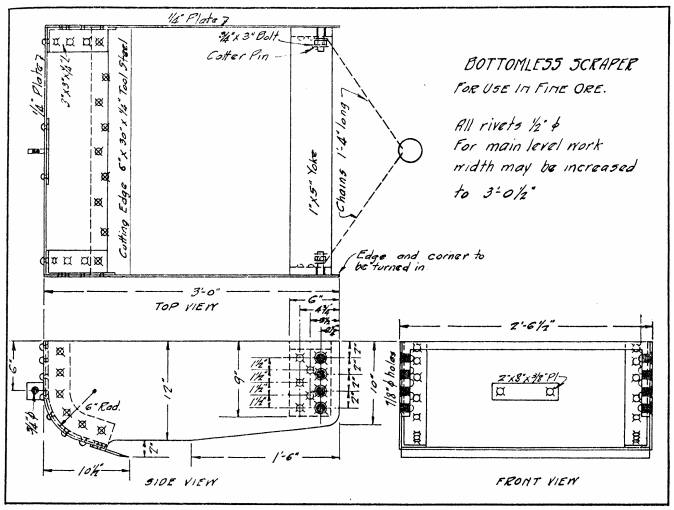


FIG. 13

Compared with regular sub-level caving, this method of mining gives increased production at decreased cost.

V. *Slushers—Radial Slicing*.—Power operated scrapers were introduced in the Oliver mines in the fall of 1920, and soon demonstrated their worth, particularly in sub-level development where the broken ore could be scraped directly into raises. In the development of main levels Hoar Loaders had been used for several years, and in this particular kind of work possessed both advantages and disadvantages when compared with

scrapers. In actual mining operations slushing showed a marked superiority over hand loading, but none over the use of gravity systems.

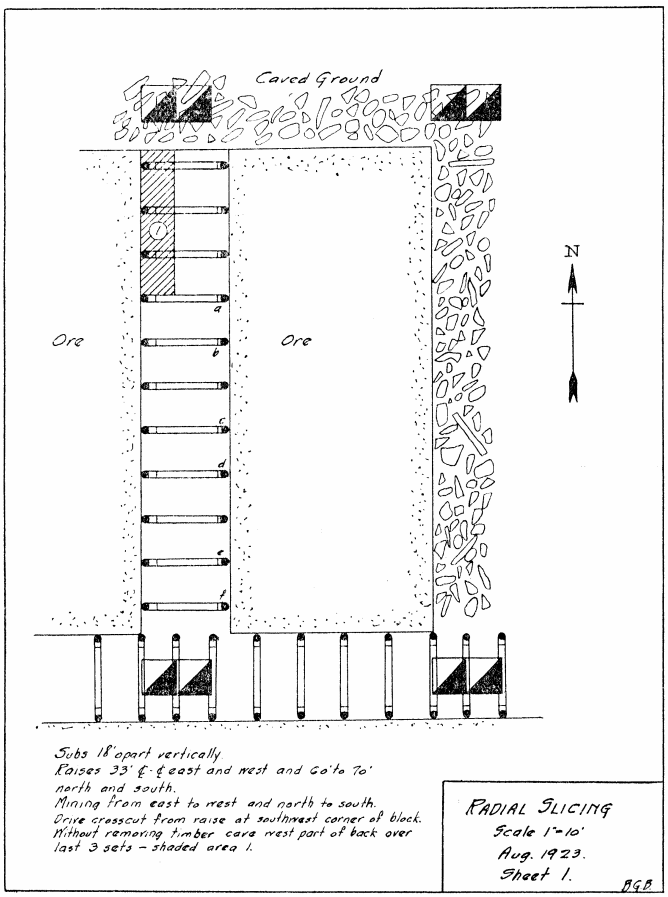


FIG. 14

Scraper hoists for general use are of the double-drum type, of 5 to 10 h.p., and operated by air or electricity. Air-operated hoists were first used, but the electric machines are coming into more general use, due to their greater speed, greater ease of operation, quieter operation, and because their use does not create an additional drain on the air supply, which in some cases may be little more than sufficient for the greater amount of drilling resulting from increased mining speed.

Bottomless scrapers are used, having a capacity of approximately ¼-ton. The scraper is shown in Fig. 13.

At the Tilden and Davis mines 1-ton scrapers are in use, operated by 27½-h.p. electric motors. These are special installations for rather unusual conditions.

When slushers were introduced most of the mines had been developed for mining by the regular sub-level caving method. Although it was quickly demonstrated that the use of scrapers and the elimination of hand-shoveling would result in increased production, it was also realized that scrapers would not work efficiently around square corners and that the mining methods then in use would have to he modified to permit the use of scrapers. One result of these conditions was the introduction of radial slicing.

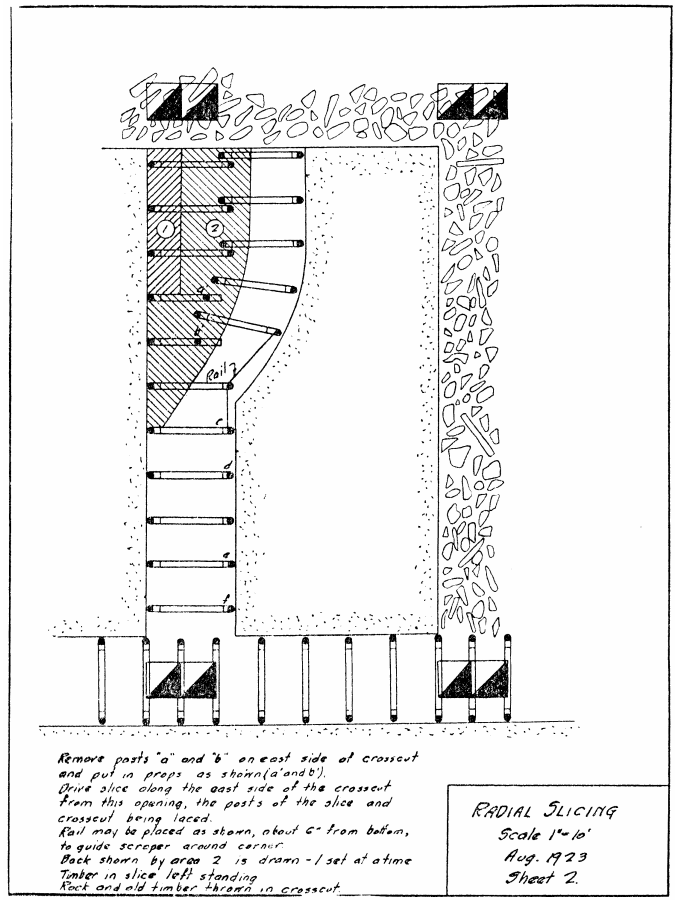


FIG. 15

Since this method of mining was devised to utilize scrapers in orebodies which had been developed for regular sub-level caving, main levels are opened exactly as for the latter method, that is, with parallel drifts 60 to 80 ft. apart, and raises 33 ft. apart.

Sub-levels are opened in the customary manner, except that all of the broken ore is scraped directly into raises. In starting to mine a block of ore a scraper hoist is set up on the south side of the raise, mounted either on a column or on skids which are held in place by sprags extending to the drift timber. If the crosscut is on the west side of the block, as shown in Fig. 14, the back over the west half of the last three sets is caved by removing two or three pieces of top lagging at each set and attacking the ore in the openings thus made. In this manner the timber is left standing to support the back not removed. Props are placed; under the fourth and fifth sets from the breast and the posts and lagging on the east side of these sets removed, as shown in Fig. 15. From this opening a slice is started at such an angle that in about 15 ft. the slice is entirely clear of the crosscut. From this point to the hanging limit of the block the slice is driven parallel to the crosscut, the west posts of the slice being “laced” with the east posts of the crosscut. The west 2 or 3 ft. of back over the slice is now caved, with the back left over the last three sets of the crosscut, and such other ore over the crosscut as can not be reached from a subsequent slice. This ore is shown by the cross-hatched area “2” in Fig. 15. As a

matter of safety, rather than take as much ore as possible from a slice, only such ore is caved as can not be reached from the next slice. Usually the back is caved for distance of 2 or 2½ ft. from the end of the cap nearest the crosscut. The remaining steps in the mining of the block are shown in Figs. 16, 17, 18, and 19. The second slice is started by placing props under the seventh and eighth sets of the crosscut and proceeding as before. This slice is driven approximately parallel to the first slice and a corresponding amount of back removed. The third slice starts from the raise and extends to the northeast, or diagonal corner of the block. For the last 20 or 30 ft. of its length this slice will run along the east boundary of the block, and all ore in the block which can be reached from the last seven sets of this slice is mined at this time. The fourth and fifth slices run from the raise to the east side of the block. From these slices the ore is caved to within 3 or 4 ft. of the drift on the south side of the block, after which all ore remaining in the block is caved into the drift.

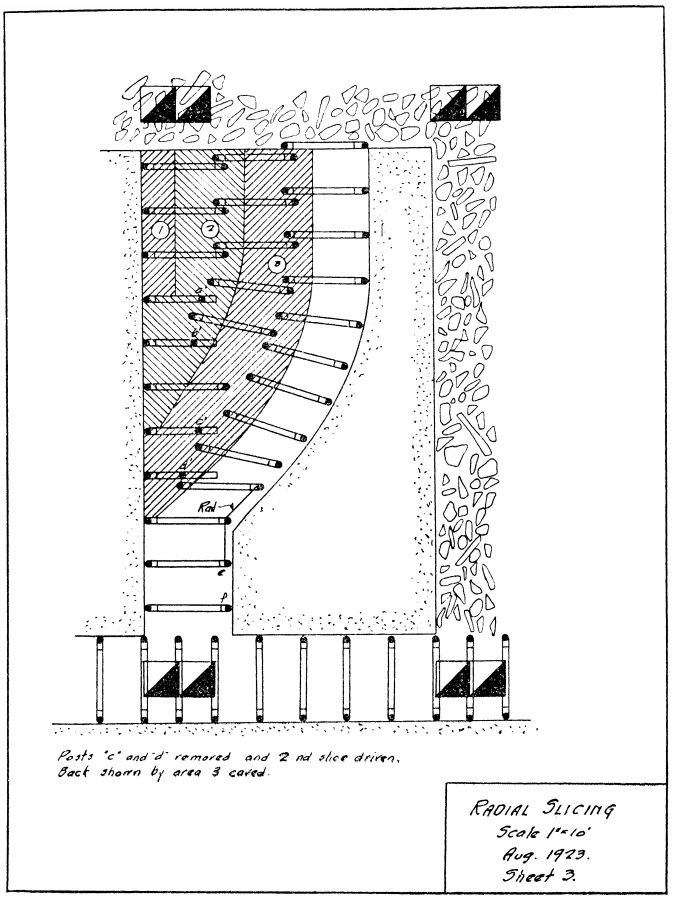


FIG. 16

The method as described is used when mining operations are proceeding from east to west, the southwest corner of the block being the last to be mined. In mining from west to east the cross-cut would be driven on the east side of the block and slices started from the west side of the crosscut.

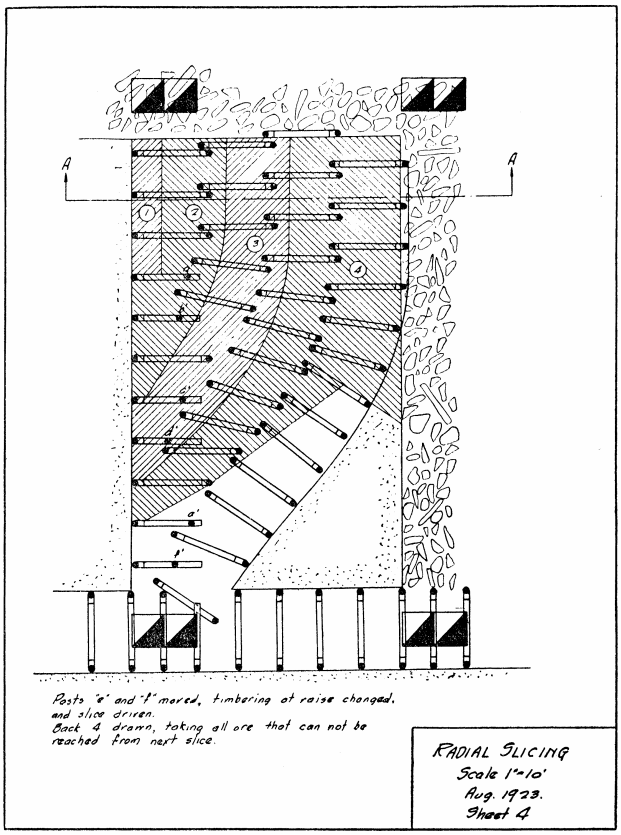


FIG. 17

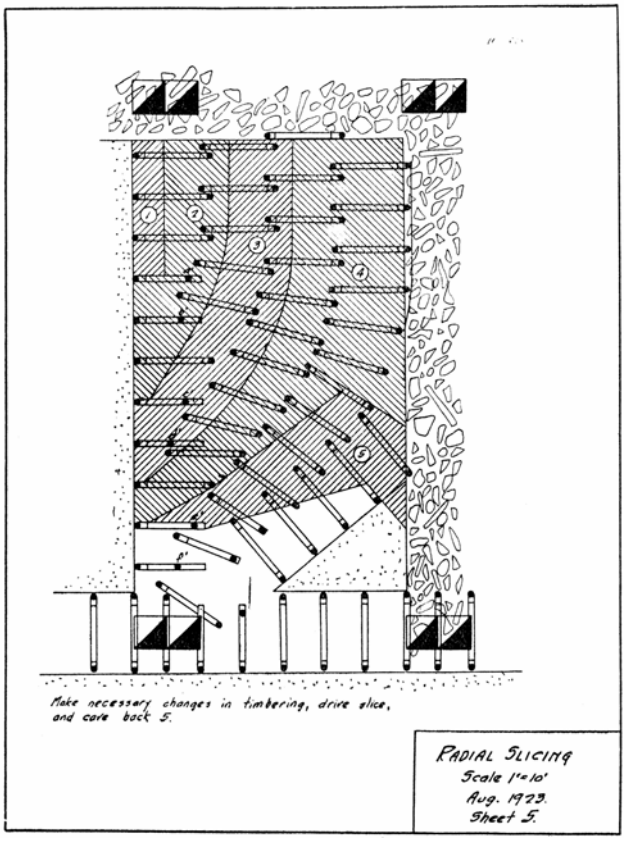


FIG. 18

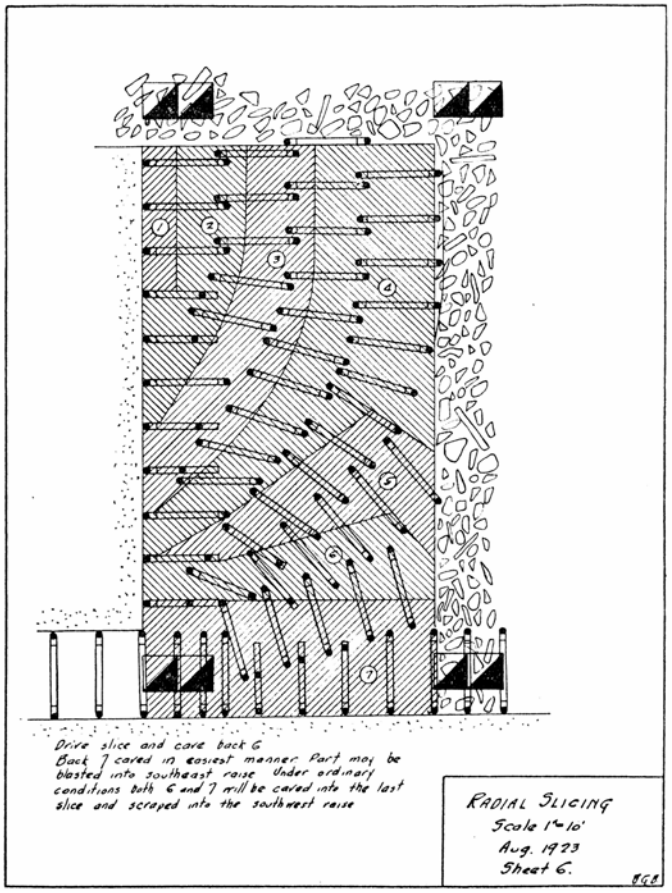


FIG. 19

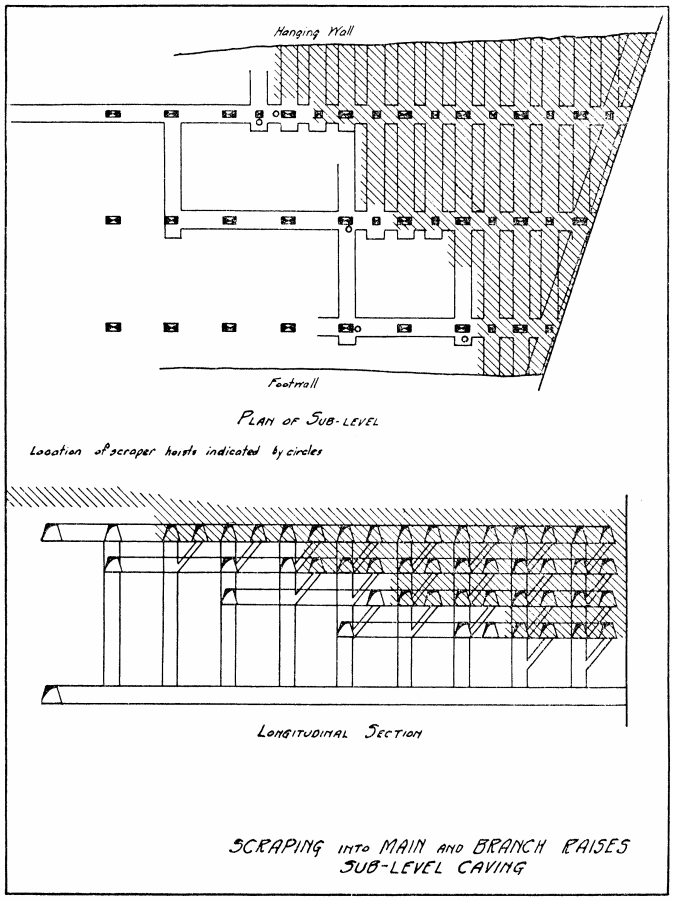


FIG. 20

Compared with regular sub-level caving, radial slicing has the following advantages and disadvantages:

ADVANTAGES—1. An increase in production of approximately 100 per cent.

2. Elimination of repair work, due to increased mining speed.

3. The entire area of the block is covered by slices, insuring high extraction.

DISADVANTAGES—1. The increased amount of timber necessary in ordinary ground. In heavy ground the timber consumption is about the same, regardless of the method used, due to the increased amount of repair work with the radial method.

2. In regular work each slice is driven in solid ground. In radial slicing one side of each slice is in the opening made by the previous slice, and in a measure unprotected from damage by the cave. This disadvantage is at least lessened, and possibly overcome, by throwing rock and old timber into the abandoned slices. This is not only an easy manner of disposing of waste material, but also helps to support the timber of the old slice, tending to prevent premature caving of the back, and should such a cave occur, deflecting the ore into the working slice.

VI. *Scraping Into Main and Branch Raises*.—A second, and possibly preferable method of using scrapers in an orebody which has been developed for regular sub-level caving is shown in Fig. 20. About 20 ft. below the mining sub a branch raise, or dog-hole, is started from each of the main raises, the branches holing to the drift on the mining sub midway between the main raises. Thus each regular 33-ft. block is served by a raise and a branch, the two ore chutes being about 17 ft. apart. To mine a block of ore, a scraper hoist is installed on the south side of the branch raise and a crosscut driven to the hanging limit of the block. When this has been done the back is caved, one set at a time, and with it a pillar 3 to 5 ft. wide on each side of the crosscut, making a total width of ore of 17 ft. that is mined from each crosscut. The scraper is now moved to the main raise and the operation is repeated, after which the hoist is set up at the end of the main raise and the drift caved. By this method a 33-ft. block of ore is mined from two crosscuts—a minimum amount of drifting and timbering. The pillars between crosscuts are small—not more than 8 ft. wide at the bottom—so that there is small possibility of leaving hogs-backs of any size.

VII. *Stoping Methods—Modifications, Variations, and Combinations*.—The mining methods described have been somewhat idealized, as is necessary in "paper mining." They are not the only methods used by the Oliver Iron Mining Company on the Gogebic Range, but

most of the ore is mined by these methods, their modifications, variations, and combinations.

Drilling and Blasting.

Four types of machine drills are in general use:

1. Power augers, using auger twist steel, in ore,

2. Jackhammers, with hollow hexagon steel, in shaft sinking and miscellaneous work.

2. Stopers, with hollow hexagon steel, for raising.

4. Water-Leyners, with hollow round steel, for dock drifting.

Thirty and 40 per cent dynamite is used in ore, and 50, 60 and 80 per cent in rock work.

Timber.

Most of the timber used underground is purchased from local loggers, who haul it to the mines by team during the winter. Small amounts of timber are shipped in by rail. Hemlock, maple, birch, elm, ash, and spruce are used for drift timber. Most of the cribbing is tamarack. Cedar lagging is used almost exclusively.

Main level timber is 8 ft. long and at least 11 in. in diameter. Sub-level timber is 7 ft. long and 9 to 11 in. in diameter. Cribbing is 6 to 9 in. in diameter and is delivered in 8-ft. lengths, later to be cut to 4-ft. lengths for underground use. Lagging is 6 ft. long.

Timber is framed by hand. It is hauled from the storage yards to the shafts by team or tractor and piled on skids preparatory to being sent underground. The customary method of lowering timber is on trucks, which are loaded on surface, pushed on the cage—one truck on each deck—and pushed off at the desired level. Underground the timber is temporarily stored in timber stations located near the shaft or sent directly to the working places. Whenever possible the timber is lowered from the main level to the subs, but when this can not be done it is usually hoisted to the subs in small timber cages running in 4 by 4 ft. raise compartments and operated by small air hoists. A typical timber cage is shown in Fig. 21.

Timber is delivered at the working places by timbermen, and placed by the miners.

Underground Transportation and Hoisting.

The ore broken on the subs is dumped in the nearest raise by the miners, using either 1-ton cars or power operated scrapers. On the main levels the ore is drawn from the raises into 2-ton gable bottom cars, which are hauled to the shaft by electric locomotives. The ore is dumped from the main level cars into shaft pockets, from which it is loaded into skips, either directly or through measuring pockets. The capacity of the skips varies from 3 to 6½ tons, and in the new Geneva shaft will be increased to 10 tons. On surface the skips dump either into the headframe pockets from which the ore is loaded into railroad cars for shipment to Ashland, or into trestle cars from which the ore is dumped on the stockpiles, later to he loaded into railroad cars by steam shovels.

Sampling and Grading.

Ore is graded according to its content of iron, silica, phosphorus, and manganese. As openings are driven an idea of the grade or grades to be mined is obtained from samples of each 5-ft. section of the openings, called footage samples. Ore from the working places is graded by samples taken each day and known as slope samples. At some of the mines samples are taken from each main level car before the ore is dumped into the pocket, from which samples of each grade from each level are obtained. On surface samples are taken from each skip of ore hoisted. Check samples are also taken of each grade from each shaft. Stockpiles are sampled before shipment, and a sample is taken from, each railroad car of ore, whether loaded from stockpile or pocket.

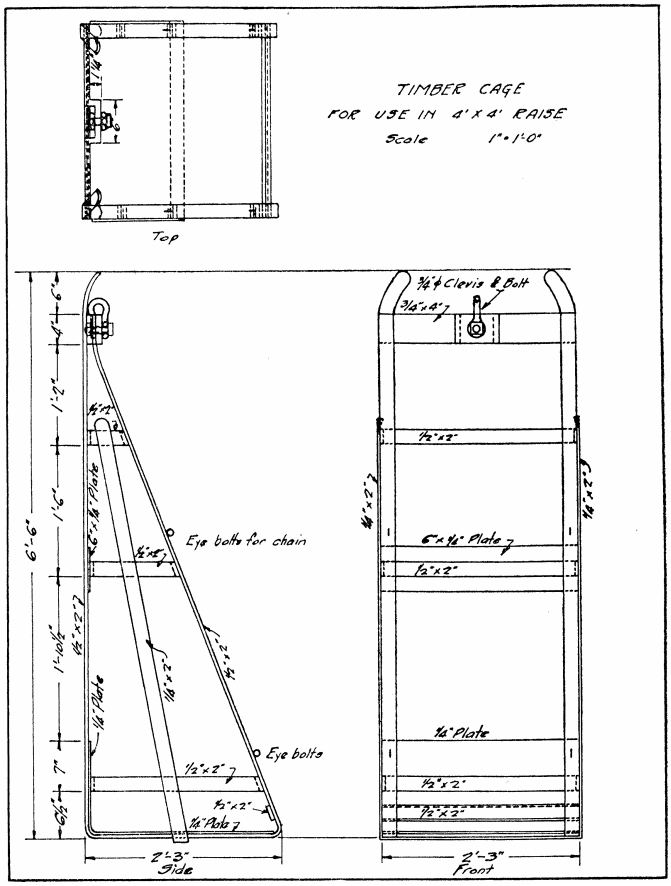


FIG. 21

Exploration and Development.

On account of the comparatively simple geological structure of the district exploration has never been a very serious problem. Since most of the mines have been opened to depths betwen 1,500 and 3,000 ft., it is not a difficult matter, using the maps of the upper levels and the adjoining- properties, to determine the approximate

locations of the intersections of the dykes with other impervious members. With this information it is possible to confine exploration to localities favorable to the formation of ore-bodies. Exploration can be done either by diamond drilling, or by crosscutting, drifting, and raising.

One method of exploration and development quite generally used is that of sinking a transfer shaft from the lowest level of the main shaft. Transfer shafts are usually small, consisting of a ladder road and a skip compartment, and lined with timber. One-ton skips are generally used, operated by small electric hoists. Shafts are sunk in the formation, usually to a depth of 300 or 350 ft. at a time. Main levels are opened from the shaft and the territory explored. If ore in sufficient quantity is found to warrant the sinking of the main shaft, crosscuts are driven and a raise put up to the bottom of the shaft. The shaft can then be deepened with a minimum amount of delay to hoisting from the upper levels. When the main shaft has reached the lowest level opened from the transfer shaft, the upper part of the smaller shaft can be abandoned and the hoist moved to the bottom level for additional sinking.

PUMPING.

All water from the Nome and East Norrie mines is collected on the 23rd level of "A" Norrie and pumped to surface by three Prescott horizontal-duplex, center-packed, pot-form pumps driven by 2,200-volt induction motors. Each pump has a capacity of 400 gallons per minute.

The water from the Aurora and Pabst mines is collected on the 23rd level of "G" Pabst and pumped to surface by two pumps similar to those at the Norrie, but of 300 gallon capacity.

Three 400-gallon pumps on the 26th level Davis handle the water from the Davis-Geneva-Puritan group.

At the Tilden mine a 400-gallon pump on the 14th level pumps the water to surface.

SURFACE EQUIPMENT.

With one exception all of the headframes are steel structures on concrete foundations. The only timber headframe is at No. 1 Geneva shaft, now inactive.

Most of the buildings erected during recent years are of fireproof construction. Concrete-block engine houses have been built at "A" Norrie, "C" East Norrie, "D" East Norrie, "E" Aurora, "H" Pabst, and the new Geneva shaft. Concrete-block change houses have been erected at "A" Norrie, "E" Aurora, and "H" Pabst. The floor and foundation plans of "H" change house are shown in Fig. 22. At the Puritan mine is a combined office and warehouse of concrete-block construction.

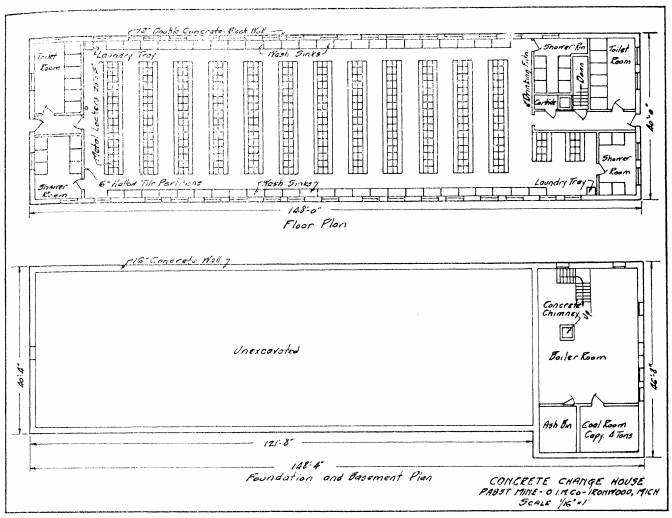


FIG. 22

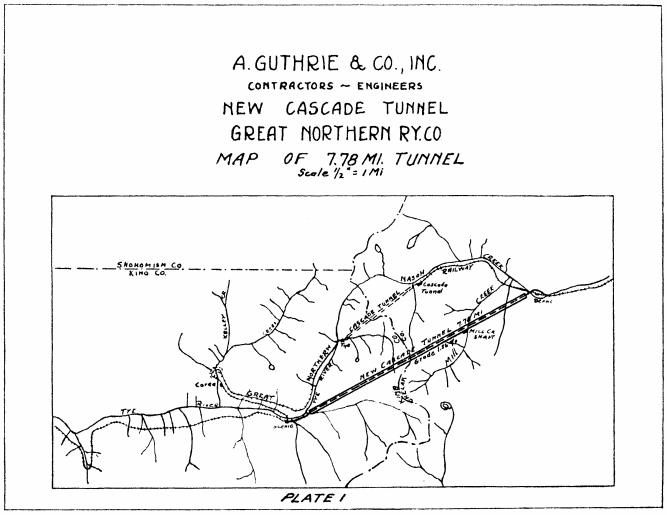
Six of the eleven operating shafts are equipped with electric hoists. Electric power for all of the mines except the Tilden is generated at the central power plant at "G" Pabst. An underground transmission line runs from the plant to the mines of the Norrie-Aurora group, and an overhead line on steel towers carries power to the Davis-Geneva-Puritan group.

THE NEW CASCADE TUNNEL FOR THE GREAT NORTHERN RAILWAY.

BY J. C. BAXTER, ST. PAUL, MINN.*

The Great Northern Railway on its route westward from the Twin Cities in Minnesota to Seattle on Puget Sound in the State of Washington crosses that portion of the Western Cordillera known as the Cascade range, at a point about 90 miles east of Seattle. A map, Plate No. 1, and a condensed profile, Plate No. 2, show the alignment and gradients of the portion of the railway involved in that crossing.

*Vice President, A. Guthrie & Co., Builders' Exchange, St. Paul, Minn.



Following J. J. Hill's historic policy of continually improving the physical property of the Great Northern, the management of the railway recently entered upon a program of electrification on its Cascade division, and in connection with this, to eliminate distance, rise and fall, curvature and snowsheds, determined upon the construction of a New Cascade tunnel, 7.78 miles in length. (We speak of this tunnel as "New" because the railway now passes under the Cascade summit through a tunnel 13,252 ft. in length, completed October 13, 1900). The alignment and grade of the new tunnel are shown on Plates No. 1 and No. 2, respectively, and a comparison of the physical features affecting maintenance and operation of the present and proposed lines is shown in Table No. 1, while in Table No. 2 are shown comparative dimensions of the old and new tunnels.

TABLE No. 1.

Table of Comparisons of Present and Proposed Lines Berne to Scenic.

	Old Line	New Line	Favorable to New Line
Length	17.67 mi.	9.99 mi.	7.68 mi.
Maximum curvature	10°00′	6°00′	.....
Total curvature	2128°	187°	1941°
Maximum grade	2.2-	2.2-	.....
Tunnel grade	1.695-	1.565-	.....
Summit elevation (subgrade)	3,382′	2,881′	500′
Total rise westward	546′	46′	500′
Total fall westward	1,325′	825′	500′
Snowsheds—total length	6.04 mi.	0.00 mi.	6.04 mi.
Bridges—total length	0.23 mi.	0.04 mi.	0.19 mi.
Tunnels—total length	3.66 mi.	7.78 mi.	.....

TABLE No. 2.

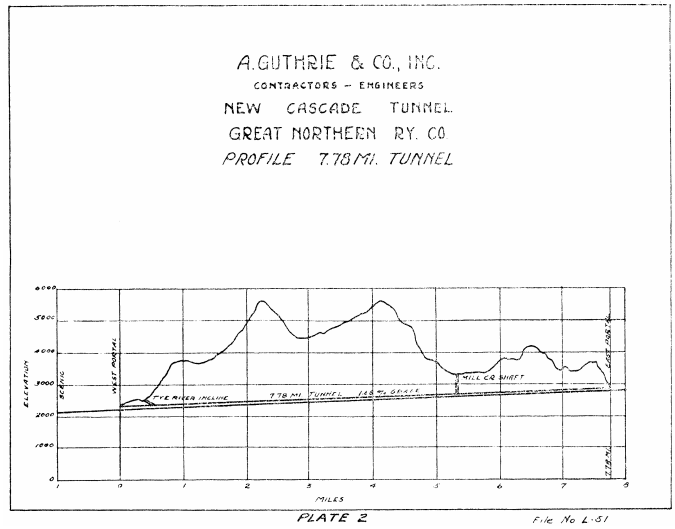
Comparative Data—Old Tunnel and New Tunnel.

	Old Tunnel	New Tunnel
Length, feet	13,873	41,148
Length, miles	2.63	7.78
Clear width	16′0″	16′0″
Clear height above top of rail	20′0″	20′10″
Subgrade elevation, east portal	3,382′	2,881′
Subgrade elevation, west portal	3,148′	2,247′
Fall in tunnel	234′	634′
Maximum grade in tunnel	1.695-	1.565-
Date tunnel started	Aug. 20, 1897	Dec. 28, 1925
Date headings met	Sept. 22, 1900	.....
Date tunnel completed	Oct. 13, 1900	.....

Note—Elevations refer to sea level datum.

In arriving at a decision to undertake a task of the magnitude of the New Cascade tunnel, it is essential the management of the enterprise have before it not only an estimate of the probable cost, but also an estimate of the probable time required to carry out the proposed work. This is so because the final cost of such a project is affected by two important items that are functions of time, namely: Interest during construction, and possible deferred maintenance,—this latter item being of great importance, as the new line eliminates approximately six miles of snowsheds with their heavy annual charges for maintenance.

Some years ago, our firm made a study of a proposed 15 mile tunnel through the Cascade range, and when in the fall of 1925, a line change involving a tunnel 7.78 miles in length was under consideration by the management of the railway, we made a study of that project, arriving at the conclusion that such a tunnel could be holed in three years. Shortly after the studies were completed, the railway company decided to carry out the change of line involving the 7.78 mile tunnel and on November 26, 1925, instructed our firm to proceed with its construction. Speed being the order of the day, our general superintendent, R. F. Hoffmark, was on the ground November 27. Camp construction was commenced on December 1, and on December 14 the first ground was moved in the approach cut for the west pioneer tunnel.



At this point, it seems best to outline the general plan of operation and method of attack by which we hope to complete the new tunnel by November 30, 1928, or three years from the date of notification to proceed with the work.

Inspection of the map and profile, Plates Nos. 1 and 2, will indicate that the two ends, or portals, of the tunnel are easy of access and therefore logical points of attack, but the Cascade range is in a region of high precipitation and has numerous springs and sturdy mountain streams. It was, therefore, possible that driving operations westward from the east portal at Berne, being down a grade of approximately 1.6 ft. per 100 ft., would be flooded out or at least seriously delayed by encountering considerable water at some one or more points. We, therefore, gave consideration to the plan of sinking a shaft in the valley of Mill Creek, where the depth of the tunnel below the natural surface of the ground is only 665 ft.

Such a shaft would permit our driving up hill towards the east end, even though considerable water was encountered because we could always get such water into properly equipped sumps behind us, and in case the east portal operations were seriously delayed would provide a method of completing the east section of the tunnel within the required time. Also, if fortune favored us and no great amount of water was encountered in either the east portal operation, or in the operations from the bottom of the shaft, we would add two additional driving faces to our total tunnel operation. The Mill Creek shaft was therefore decided upon.

Since the time this decision was arrived at, that is November 26, 1925, the operations from the east end of the Moffat tunnel in Colorado have progressed to the summit near the center of the tunnel and started down grade west of the summit and have been flooded out. It is the possibility of an occurrence of this kind in the New

Cascade tunnel that led to the decision to sink the Mill Creek shaft.

The Mill Creek shaft obviously cuts the 7.78-mile tunnel into two segments,—the eastern 2.41 miles in length, and the western 5.37 miles in length, and as the speed of driving operations westward and down hill from the shaft is somewhat problematic, for the same reasons as previously advanced in regard to the operations westward from the east portal, the real problem resolved itself into how fast we could drive up hill from the west portal. A careful study of various methods of attack resulted in our selection for this operation of a pilot or pioneer drift, or tunnel, outside of the section of the tunnel proper, together with a heading in the center of the tunnel section, the two being connected by crosscuts at intervals of 1,500 ft.,—the center heading to be later stripped or enlarged continuously from the west portal eastward at whatever speed could be made with the pioneer tunnel. Plate No. 3 illustrates this method of attack, together with sections of the full tunnel and sections showing the method of ring drilling.

The pioneer tunnel was placed 66 ft. to the south of and parallel to the center line of the tunnel proper,—the distance of 66 ft. being arrived at as our best judgment of the distance necessary to prevent failure by crushing of the rib between the tunnel proper and the pioneer. In the first Simplon tunnel in Switzerland, the pioneer tunnel was 56 ft. off center with the main tunnel, and the rib failed by crushing at several points. The center heading method of course depends upon mucking facilities being provided, which will permit the face of the enlargement to be advanced at a speed greater than any possible speed that may be obtained in the pioneer tunnel, and this end we obtain by placing a Model 40 Marion railroad type shovel mounted on caterpillars and operated by compressed air in the enlargement operation.

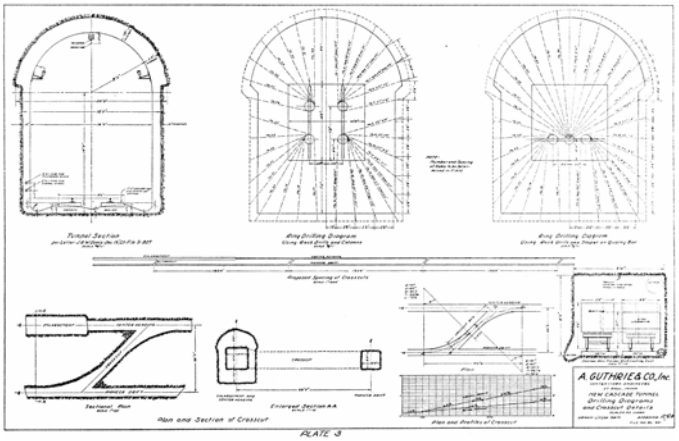


PLATE 3

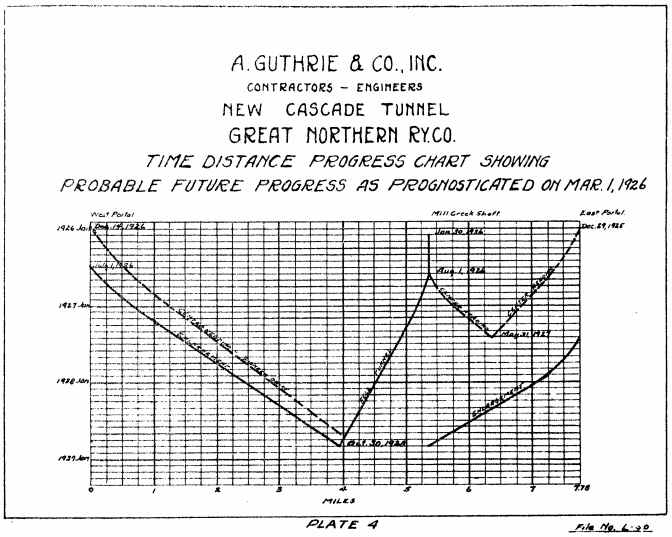


PLATE 4

File No. L-20

For the eastern segment of the tunnel from the Mill Creek shaft east, our studies indicated the use of a center heading only as time was not such a controlling factor and as the center heading would provide the most economical method. In the use of the center heading method without a pioneer tunnel, a second opening is required and this condition will be obtained by driving the center heading west from the east portal and east from Mill Creek shaft until they meet, then commencing enlargement operations at the east portal, the men, tools, air and water lines and explosives for the ring drilling and blasting for the enlargement reaching the working face from Mill Creek shaft, while mucking operations go on continuously at the face,—the muck being hauled out through the east portal.

Having decided upon the general plan and method of attack, we were in a position to make a prognostication as to probable progress and this is shown by time-distance curves in Plate No. 4. At the time of preparing this paper, the various operations are all under way, the status as to progress on September 1, 1926, being shown in Table No. 3.

PLATE 5

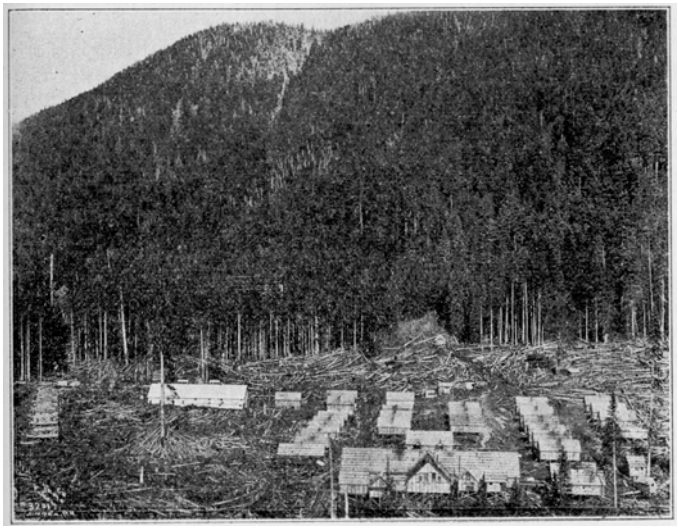


PLATE 6

PLATE 7

TABLE No. 3.

In Advance of Schedule.

	Feet	Days
West portal, pioneer	1,743	76
East portal, center heading	1,298	86

Behind Schedule.

	Feet	Days
Mill Creek shaft, east	81	15
Mill Creek shaft, west	80	15

After laying out the above method of procedure and clearing the ground in the vicinity of the west portal of a dense stand of timber, it was discovered that for a distance of approximately 2,000 ft., the line of the tunnel would penetrate an old slide, and in order to avoid the delay to the entire west portal operation that would necessarily occur while penetrating such material, an incline shaft at an angle of 30 deg. was sunk on the line of the pioneer tunnel in the gorge of the north fork of Tye River, as indicated on the profile, Plate No. 2, and the pioneer tunnel advanced from that point.

The figures in Table No. 3 for the west portal pioneer are for the advance from the Tye river incline measured as from the portal, although there yet remains 40 ft. of ground to break through to connect up the two portions of the pioneer tunnel. This breakthrough will not be made until crosscuts No. 1 and 2 are connected by the center heading, at which time the pioneer operation can proceed uninterrupted by the break-through, passing around it by way of crosscuts No. 1 and 2 and the center heading.

The operations of driving the new Cascade tunnel are situated geographically in a remote mountain wilderness,—the only marks of civilization being the main line of the Great Northern railway which lies in close proximity to the east portal, and is about one mile from the west portal, together with a wagon road over the summit from Scenic to Berne, impassable on account of snow except during the summer. Therefore, it became necessary, before any real progress could be made, to construct camps and service buildings, together with living quarters for married employees, at all of the points of attack, and to construct a wagon road about three miles long from Berne on the main line of the railroad to the Mill Creek shaft. The difficulty of constructing these camps and the wagon road will be appreciated from the statement that timber standing in some instances 50,000 ft. B. M. to the acre, had to be cleared and disposed of before the construction of camps could proceed. Plates No. 5, 6 and 7 are photographs of the East Portal, Mill Creek and West Portal camps respectively, and shows clearly the stand of timber.

Each camp is provided with change houses, or “drys” equipped with steel lockers and shower baths, adjacent to the underground openings, and also with wash houses and toilets conveniently spaced. The camps are all provided with running water for domestic use and fire protection, and with sanitary sewers discharging into septic tanks. They are electrically lighted and the cook camps have electrically-driven refrigerator plants for the proper care of food. Each camp is provided with a recreation building where various forms of

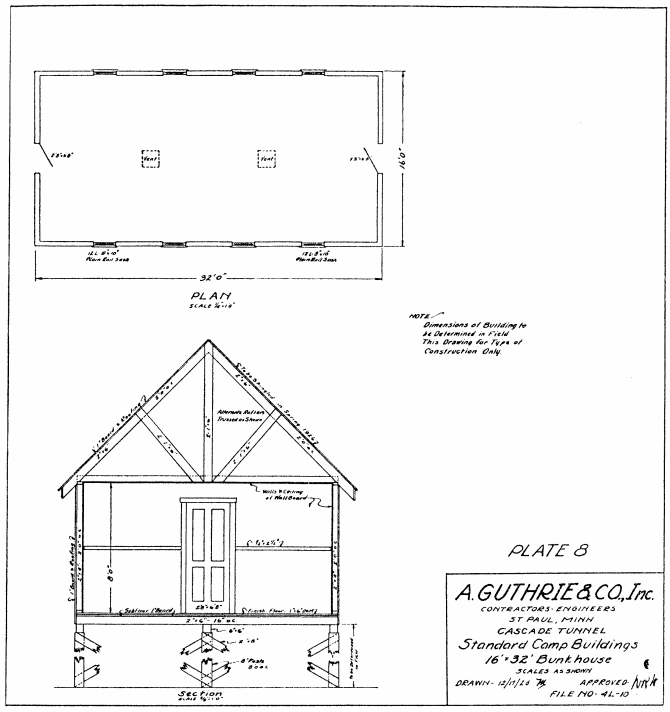
entertainment, including moving pictures, may be held and in addition there are buildings “devoted” to the use of the men for reading, writing, card playing, etc.

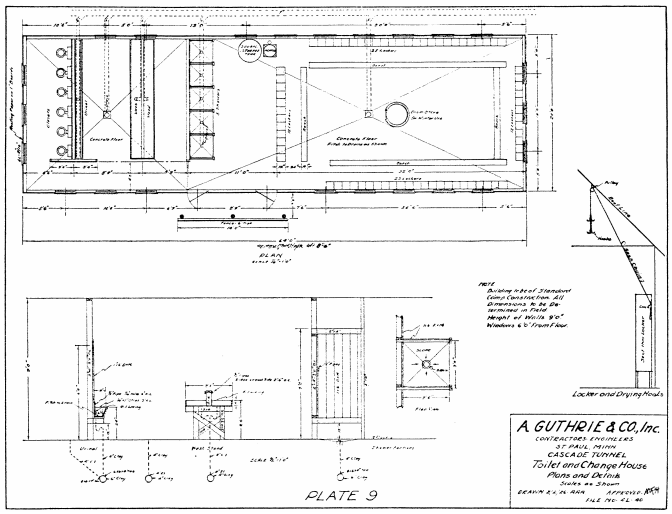
Adjacent to each camp there has been constructed a group of small dwellings for the use of married employees, and in proximity to these dwellings, there is provided a school house and school teachers’ dwelling. Each camp is provided with first-aid stations at the various openings and with an emergency hospital presided over by a resident physician.

Plate No. 8 shows the general type of camp construction,—the height above the ground being provided to avoid the expense of grubbing the surface and to aid in removal of snow, which in the vicinity of the tunnel varies from two to 12 ft. in depth. The steep pitch of the roofs was also dictated by snow conditions.

Plate No. 9 shows the general type of “dry” or change house and Plate No. 10 the type of married quarters.

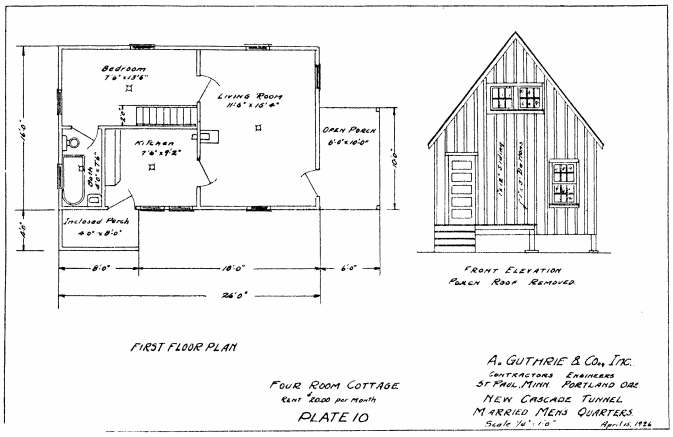
One of the vital features of a successful tunnel-driving operation is a reliable source of power, and it was determined to start all operations with gasoline-driven portable air compressors and lighting plants pending a study of the power situation. This study developed that the Great Northern railway could in a few weeks furnish us with sufficient power from their Tumwater hydro-electric plant, about 25 miles east of Berne, to carry the entire load of the east portal and Mill Creek operations, and that we could secure in the course of eight or nine months an adequate supply of power from the Puget Sound Power & Light Company for the west portal operations.





With the above in mind, and in order to carry the west portal load during the period that would elapse while a transmission line was constructed by the power company, that is some eight or nine months, a generating plant producing 2300-volt, 3-phase, 60-cycle current and driven by 1,200-hp. Fairbanks, Morse & Company type “Y” oil engines, was installed at Scenic, a station on the railway, about one mile west of the west portal, and a similar plant of 720-hp. was installed at Mill Creek shaft as a stand-by to furnish power for the shaft pumps at any time when the transmission line might be out of service. Power from the Great Northern hydro-electric plant at Tumwater was delivered early in the year, and power from the power company has recently been delivered at Scenic so our operations are now on an outside power basis, and all small portable outfits have been taken out of service.

Power is received from the railway company’s plant at Tumwater in the form of 3-phase, 25-cycle, current, and the frequency changed to 60-cycle through a frequency changer near the mouth of Mill Creek from which point it is transmitted at 2,300 volts to the east portal and Mill Creek shaft, at which voltage it is utilized on all primary motors. Power at Scenic is received from the power company as 3-phase, 60-cycle, transformed to 2,300 volts and utilized at that voltage on all primary motors at that point.



All underground lighting circuits are 3-phase, 60-cycle, 220-volts, while lighting circuits on the surface generally are no volts. Underground haulage is all electric, the current used being direct current at 275 volts, furnished by motor-generator sets driven by 3-phase, 60-cycle, 2200-voit motors.

The first motor-generator sets are installed outside of the tunnel, but additional sets will be installed in sub-station rooms, as the length of the tunnel becomes too great for 275-volt direct current transmission.

The pioneer tunnel and center heading operations are supplied with 6-ton 24-in. gage General Electric trolley locomotives equipped with gathering reels, holding 500 ft. of cable. The enlargement operations are supplied with 20-ton 36-in. gage General Electric trolley locomotives, also equipped with gathering reels holding 500 ft. of cable.

In addition to the above, each working opening is supplied with one 6-ton General Electric combined trolley and storage-battery locomotive, which is kept on outside work and is available for rescue purposes at any time the trolley line is out of service.

Drilling in all operations at the east portal is performed with Ingersoll-Rand R-72 drifters, using hollow 1¼-in. diameter new-process crucible steel. The sinking of the Mill Creek shaft was carried out with Chicago Pneumatic CP-50 sinkers using 1¼-in. diameter round steel and all operations at the west portal are being carried out with Denver-17 drifters using the same steel.

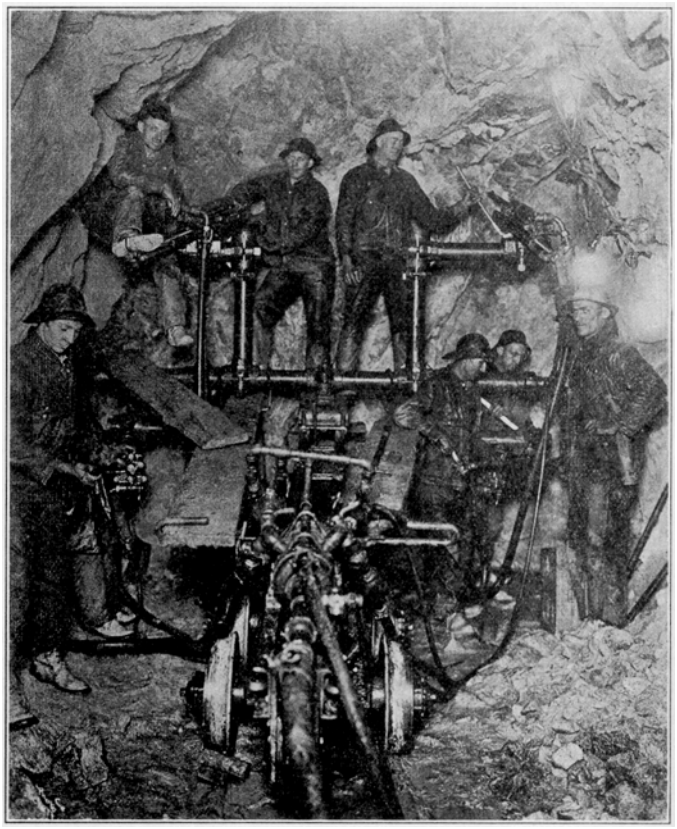


PLATE 11

Drilling in the east portal center heading is carried on from a horizontal bar in the usual practice of mounting the bar over the muck pile and carrying on drilling and mucking operations simultaneously, but in the west pioneer tunnel, a Sullivan drill carriage, illustrated in Plate No. 11, is installed. The use of a drill carriage necessitates dividing the cycle of a round into clearly defined operations, each one being carried on separately, and while at first glance this does not appear to be the most economical method that could be devised, it is by far the fastest, and consequently the most economical in this case, and will be used in drifting operations from Mill Creek shaft east and west.

Steel sharpening shops, located at each camp, are all equipped with Sullivan sharpeners and furnaces,—the furnaces being controlled by Brown automatic control pyrometers. This equipment is giving good satisfaction and we are gradually getting to the point where broken bits or shanks are of almost unknown occurrence.

Compressed air is furnished for all of the camps by two-stage compressors driven by 3-phase, 60-cycle, 2300-volt synchronous motors direct-connected to the compressors, the compressor capacity in the various camps being shown in Table No. 4.

TABLE NO. 4.

	Actual air per machine	Actual total air
East Portal—		
3—Sullivan 18-11-14 angle compound compressors	950	2,850
Mill Creek—		
3—Sullivan 18-11-14 angle compound compressors	950	2,850
1—I. R. "Imperial" type XRE-2 Duplex 19-11-14 compressor	988	988
West Portal—		
5—Sullivan 18-11-14 angle compound compressors	950	4,750
Total actual air, entire job		11,438

Mill Creek shaft is a four-compartment shaft designed for balanced hoisting, a cross section being shown in Plate No. 12. The shaft is equipped with two hoists, the primary being an Ottumwa single-drum hoist handling two 70-cu. ft. capacity Kimberly skips in balance at a maximum speed of 885 ft. per minute, and has a capacity of 140 tons per hour,—the secondary being an Ottumwa single-drum hoist handling the man and material cage at a speed of 700 ft. per minute.

As previously mentioned, we have always been apprehensive concerning the amount of water we may encounter, and consequently, as a precautionary measure, Mill Creek shaft is somewhat over supplied with pumps. First, we had on hand two triplex pumps good for 600 g. p. m. against a 400-ft. head. These pumps are installed in tandem, one in the 300-ft. station and one in the 665-ft. station, and they are now handling the small amount of water we have so far encountered, that is about 100 g. p. m. To stand by these pumps we have one 5-in. 4-stage Fairbanks, Morse centrifugal pump, having a capacity of 600 g. p. m., direct-connected to a 200-hp. motor at the 665-ft. station and as an insurance against a sudden development of water, have also a 5-in. 4-stage Fairbanks-Morse centrifugal pump of 1,000 g. p. m. capacity direct-connected to a 250-hp. motor on the same level. This gives an emergency pumping capacity of 2,200 g. p. m.

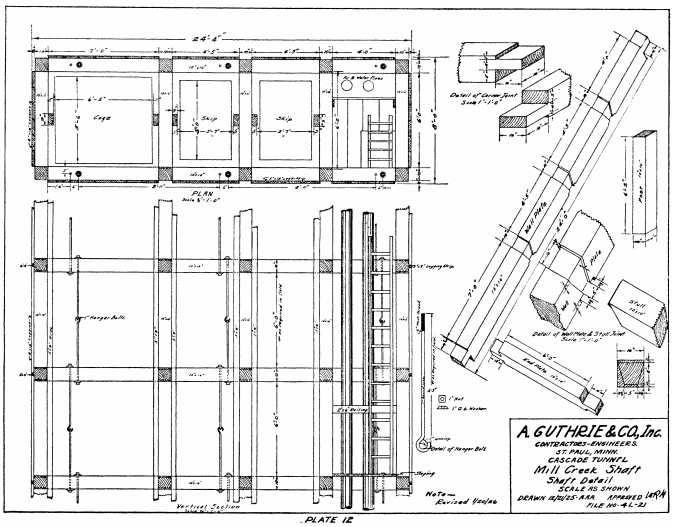


PLATE 12

All mucking in the drifts is done by Myers-Whaley machines, such as illustrated in Plate No. 13. Practically every other machine on the market has been tried and for speed and general reliability, none can compare with the Myers-Whaley,—a round of 32 cu. yds. of hard coarsely-broken granite having been loaded by one of these machines, including the time occupied in cleaning up the fly rock, in one hour and 30 minutes.

The mucking in the enlargement will be done by Model 40 Marion railway type shovels, mounted on caterpillar tractions, and operated by compressed air. Longitudinal and cross sections of the tunnel showing the working conditions for one of these shovels arc illustrated in Plate No. 14.

The Model 40 shovels were originally steam shovels and have slide-valve engines, and in order to prevent freezing at the exhaust, the boilers have been removed and electrically-heated air receivers 4 ft. in diameter by 7 ft. 6 in. long mounted in their place. These receivers are now equipped with 18 General Electric G.C. 220-volt immersion heating units connected at no volts to prevent destruction by overheating—(our experiments indicate an indefinitely long life for these units when so connected). The heating elements so connected deliver as heat units 22.5 kw. of energy. However, we have not gone far enough as yet along this line to determine if we are supplying sufficient heat for colder weather, but as the enlargement operations proceed, we expect to gather some interesting data on this subject. Each receiver is equipped with a Brown indicating thermometer, the indicating element being mounted in front of the shovel operator, together with a switch controlling the heating elements in order that the temperature may be kept within practical limits.

All material removed from the various drifting operations is loaded into 50-ft. capacity 24-in. gage side-dump cars, manufactured by the Koppel Industrial Car & Equipment Company and shown in Plate No. 15. The selection of this type of car was governed by the idea of reducing the number of switches per round by securing the largest cubic capacity car that could be loaded within the limits of the Myers-Whaley shovels and that could pass each other within the 9 ft. limit of the width of the pioneer tunnel. The Koppel car fulfilled these requirements, but is rather difficult to dump, special dumping devices being required to accomplish this rapidly. However, this difficulty is not a serious one, as all of these cars at the west end are clumped into a dock and the material transferred to 6-cu. yd. ears for final disposition. Being dumped into a dock, the installation of dumping devices was a simple matter.

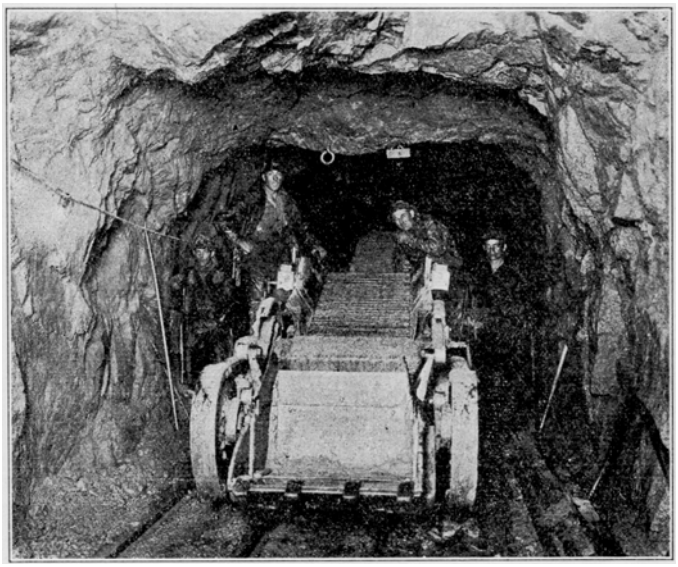
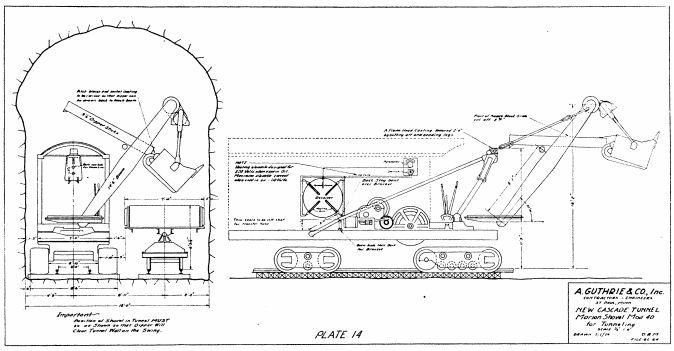


PLATE 13



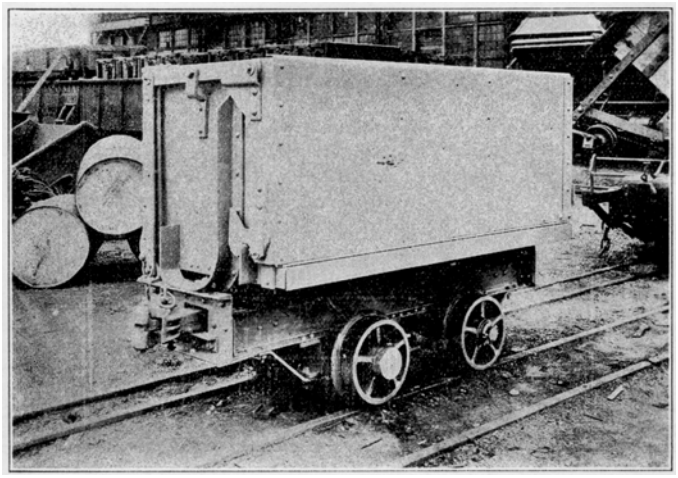


PLATE 15

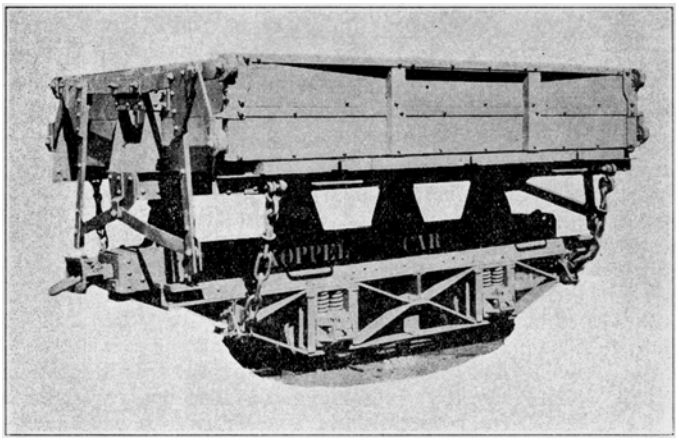
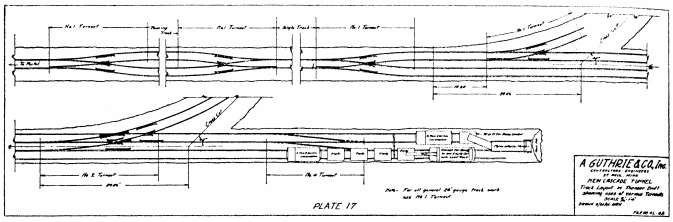


PLATE 16

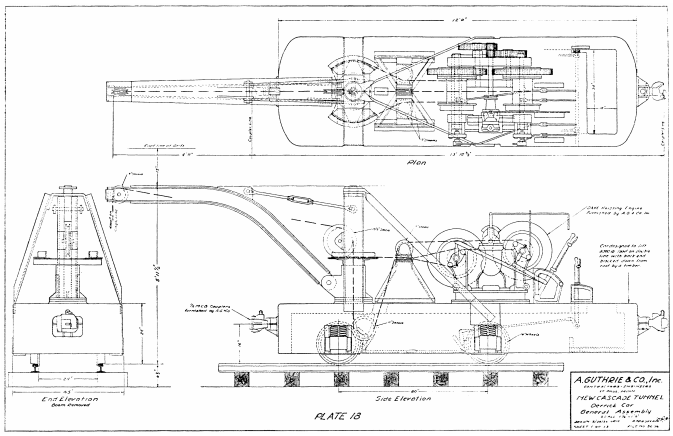
The enlargement shovels will load into 6-cu. yd. 3-ft. gage side-dump cars manufactured by the Koppel Industrial Car & Equipment Company and illustrated in Plate No. 16. The selection of this car was governed by the same line of reasoning as applied to the selection of the drift cars,—that was, to reduce the number of switches by securing the largest possible car that could be loaded along side a Model 40 shovel, within the range of that machine, and the clearance available in the full tunnel section.

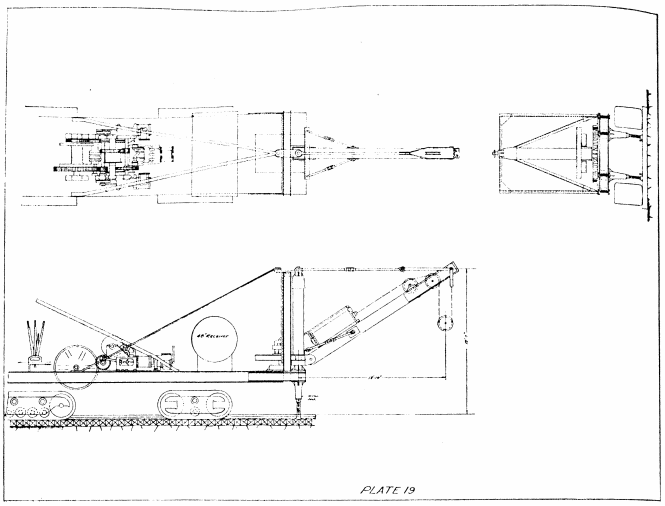
These 6-cu. yd. side-dump cars have been found as easy to operate as the old 4-yd. cars of similar type, that have been standard as 3-ft. gage equipment for many years.

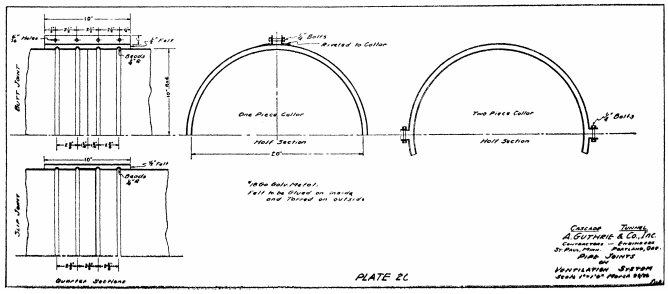
Reference has been made in the description of the cars to the necessity of saving time in switching, this being accomplished by increasing the size of the cars to the practical maximum, but even so there remain just so many cars to be switched for each round, and as you are all familiar with the inroads switching time makes in the 480 minutes of an 8-hour shift, you will realize the necessity of cutting these delays to a minimum, when the statement is placed before you that each minute delay per round in the west pioneer tunnel will delay the eventual completion of the tunnel 50 hours. In order to reduce this delay we determined upon a transfer method of switching, wherein a crane immediately behind each loading machine picks up an empty car and transfers it to a loading track immediately the loaded car is hauled clear of the shovel. This method is shown diagrammatically in Plate No. 17, while Plate No. 18 illustrates the 24-in. gage transfer hoist in use in the drifting operations. The transfer hoist serving the Model 40 shovels with 6-yd. cars in the enlargement operation is mounted on the rear of the shovel frame and supported by two 10-ton jacks. This hoist is shown in Plate No. 19.

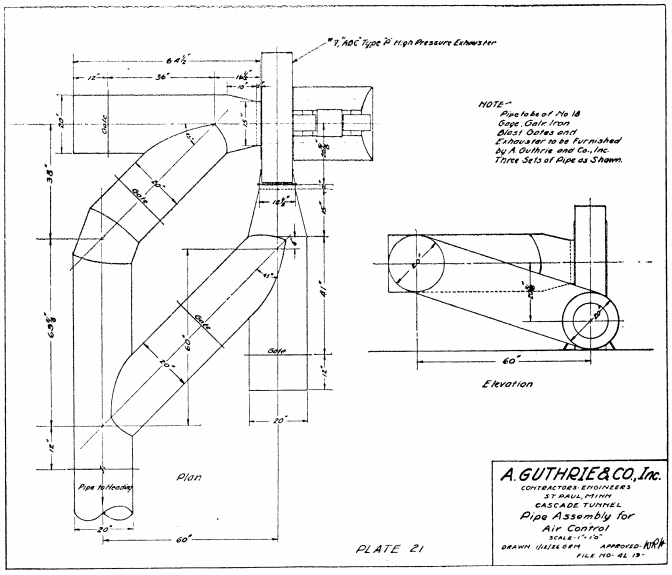


Ventilation is of course one of the major problems in an operation such as the Cascade tunnel and our studies along this line have led to the adoption of various sizes and types of fans suitable for each particular case, manufactured by the American Blower Company, and to the adoption for all secondary ventilation of 20-in. diameter 18-gage galvanized rivetted and soldered ventilating pipe connected by a special packed joint, illustrated in Plate No. 20, while for reversing the air current from blowing to suction, reversing gates as shown in Plate No. 21 are used. Primary ventilation of the west portal, pioneer, and main tunnel and secondary ventilation beyond the return point of the main air current are handled as shown diagrammatically in Plate No. 22—ventilation in all other openings being obtained by combinations of fans along similar lines.





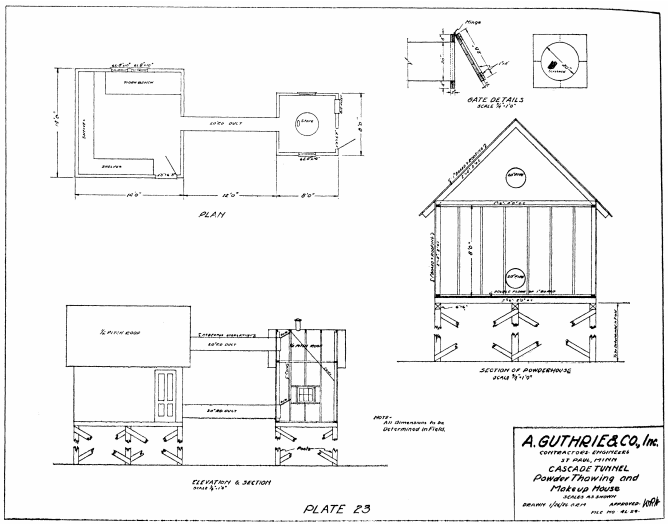


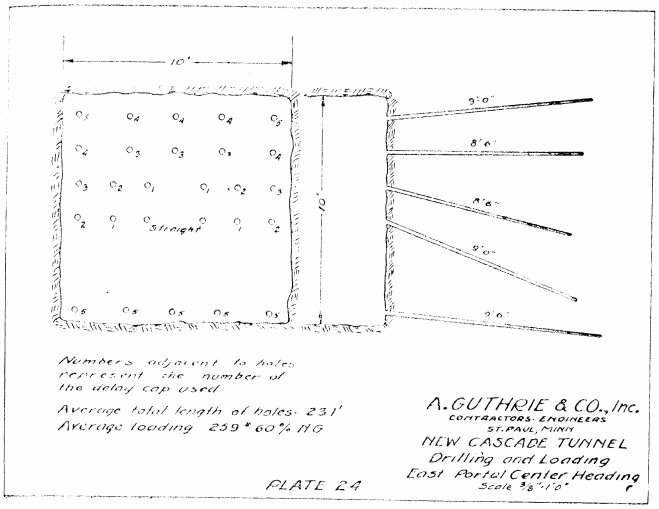


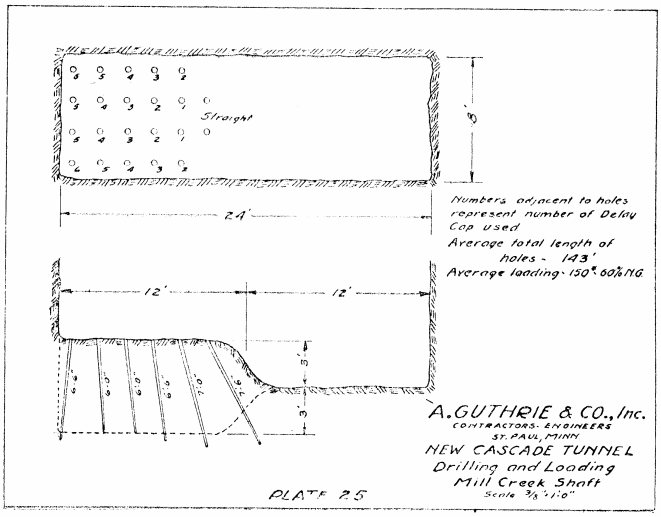
The laying of pipe lines for compressed air and water is one of the lesser problems in tunnel operations, but still one of considerable magnitude, as the main air and water lines must be kept close up to the face, and the work of laying them must be performed without interfering with the major operation of drifting. After careful studies of the various pipe materials and supplies available, we decided upon the use for all pipe lines over 2-in. in diameter of so-called "gas line" pipe, which is about 50 per cent lighter than standard wrought iron pipe of equal diameter, this pipe being connected with Dayton couplings which are very easily applied, do not require any threading of the pipe and permit each length of pipe to be laid several degrees out of line. This selection of pipe and couplings has been found entirely successful.

Drill steel is hauled into the working; places in special cars provided with compartments, and a full supply of steel for one round is loaded in one car, taken in, used, and brought back to the steel shop for refitting.

As the length of the operations increases, it becomes necessary to transfer men to and from work, and passenger cars have been constructed, on which each shift will be hauled to the working-face and the returning shift brought out, the change of shifts being made, as the saying goes "at the handles of the drills." These passenger cars consist of flat cars, provided with a seat down the center on which two ranks of men can ride sitting back to back.





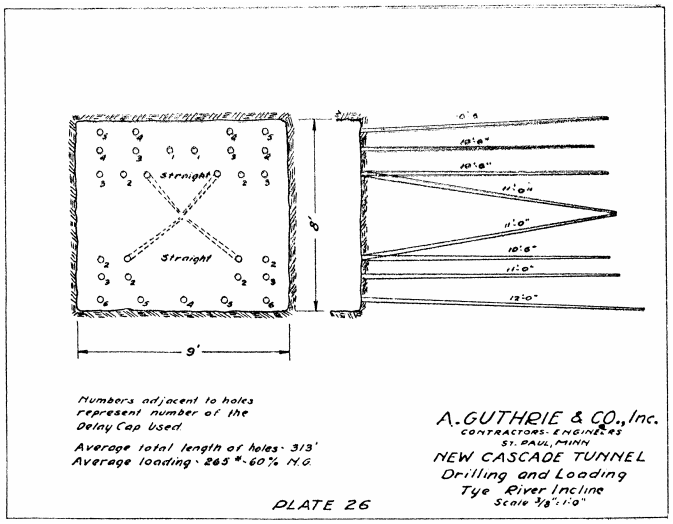


Explosives and primers are assembled for each round in powder-fitting houses above ground, the houses being

all uniform in design, as illustrated in Plate No. 23, and the powder for each round is hauled to the face in a special locked car constructed entirely of wood above the trucks and lined throughout with rubber. Firing, without exception, is done electrically, using the 220-volt lighting circuit for energy.

The general practice of drilling and loading in the various operations is shown in Plates No. 24, 25 and 26.

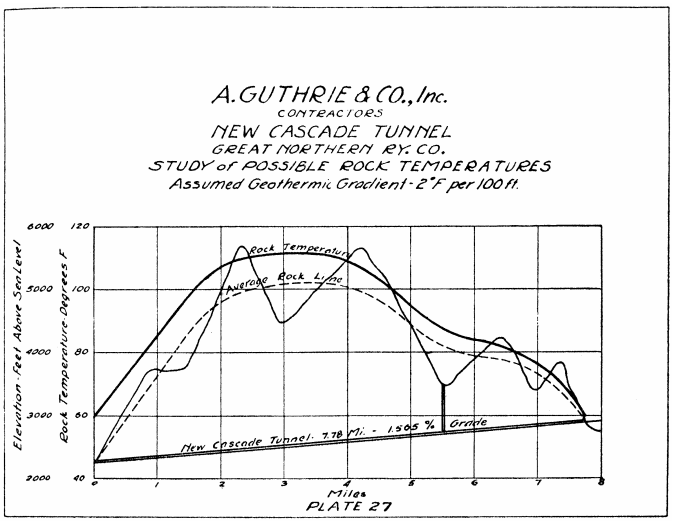
In addition to the special tunnel plant, the west portal camp has been supplied with a first-class machine and blacksmith shop for general repair work, and a small shop for emergency repairs has been erected at the east portal.



As part of our examination of the difficulties to be expected in driving the New Cascade tunnel, a study of the probable maximum ground temperatures that might be encountered was made and the results of these studies are shown in Plate No. 27.

The probable rock temperature line is based on a natural surface ground temperature below the influence of seasonal variations of 60 deg. F. and a geothermic gradient of 2 deg. F. per 100 ft. vertically, measured to an average rock line. The base temperature and rate of increase used are both high and even so, it seems probable we will not encounter excessive temperatures.

The headframe for Mill Creek shaft, Plate No. 28, was constructed of timber, as it is possible to hew sticks of any size or lengths under 20 by 20-in. by 100 ft from fir trees standing in the vicinity. In order to commence sinking Mill Creek shaft quickly, a small temporary headframe was erected on the site of the shaft, as shown as “B” in the plate, and immediately after this, the erection of the permanent headframe was commenced.



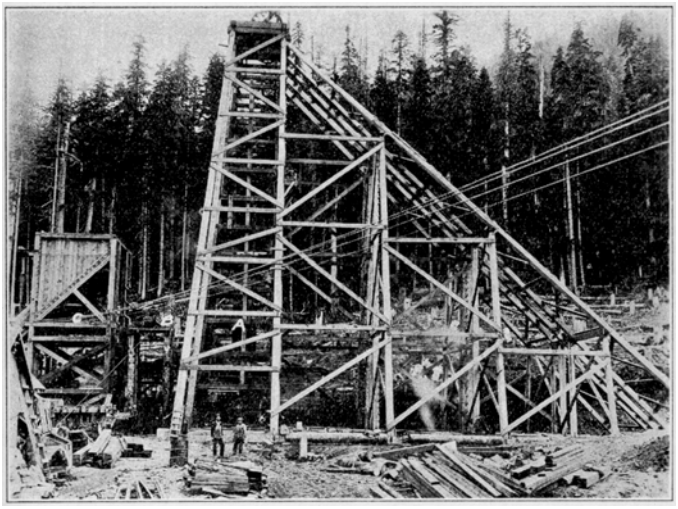


PLATE 28

In order that there might he a minimum delay in the sinking of the Mill Creek shaft, the headframe and its necessary pockets were built in two sections as shown at TV’ and “C”—the section *VCS being built in the position it was eventually to occupy,—section “A” being built back from the shaft about 15 ft. from the position shown in that photograph.

After the completion of section “A,” it was moved forward to the position shown. The shaft timbering was prepared with guides and guides to match them were erected in the headframe. The head frame was then lubricated on its skids by forcing hard grease through the skids on to the sills through pipes, to which compressed air at 100 lb. pressure was applied. The headframe, section “A,” was then skidded forward with five 15-ton jacks into its exact position over the shaft, section “B” having been torn down immediately previous to this operation. The entire delay to the sinking of the shaft due to moving section “A” into position was only nine hours. The headframe, section “A,” is approximately 80 feet in height and the work of moving it was performed without the occurrence of any unforeseen difficulty.

The ideal time-cycle per round in the various headings is well illustrated by a time-cycle from the west portal

pioneer taken on a day when five rounds were pulled and mucked in three shifts. This time-cycle is shown in detail in Table No. 5 and represents what may be accomplished under ordinarily favorable conditions.

TABLE No. 5.

Round or Cycle of Operations, Tye River Heading, August 25, 1926

Time of operations	= One cycle
Blast	= 7:10 a. m.
Ventilation	= 27 minutes
Enter drift, clean up fly rock with Myers-Whaley and hand muckers	= 38 minutes
Muck main muck pile	= 1 hour 22 minutes
Remove mucker, set drill carriage	= 38 minutes
Drilling	= 1 hour 17 minutes
Load and retire	= 18 minutes
Blast	= 11:50 a. m.
Time of operations	= 4 hours 40 minutes

28 holes, average depth 8′6″
195 lbs. powder, DuPont 60% gelatine
7′6″ advance
9′x10′ cross section
4 drills on carriage (Denver No. 17)
Rock, altered granite
16 men, including shifter and mucker boss underground
28 50-cu. ft. Koppel cars loaded

Speed being of such great importance, the entire job is operated on the system of changing shifts at the face and working-three shifts every day including Sundays, holidays, the Fourth of July, and Christmas.

During the month of October just past, the west portal pioneer operation has made a world's record for drifting, that is, 1,157 feet working one face only, through solid granite with a drift 8x9 ft. in cross-section in thirty-one calendar days.

This progress in the various operations by months, and total to November 1st, are shown in Table 6.

TABLE No. 6.

New Cascade Tunnel—Progress to Date By Months.

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Total
Pioneer drift	40	190	224	226	100	424	458	485	83	527	1,157	3,914
Incline (b)*	....	40	82	178	376	651	717	676	937	....	.....	3,657
West portal center heading	....	....	....	....	....	56	497	548	699	639	216	2,655
West portal enlargement	....	....	....	....	....	....	....	....	411	348	455	1,214
East portal center heading	5	128	331	475	495	657	707	760	665	954	890	5,967
Mill Creek shaft *	....	....	61	106	123	78	158	133	....	....	.....	659

*Completed.
(b) This is total footage driven by incline crews and includes incline proper.
Total pioneer driven from foot of incline is 3,424′.

Should any member desire more detailed information as to the various phases of operations at the new Cascade tunnel, it will be gladly furnished upon request to the writer.