Open Pit Mining Operations

James A. Simon

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Report on
OPEN PIT MINING OPERATIONS

In Partial Fulfillment of
the Requirements
for
Mining 68
Montana School of Mines

Submitted to
Professor Koehler S. Stout
Professor of Mining

by
James A. Simon
Butte, Montana
May 10, 1957
Report on
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May 10, 1957
1221 W. Porphyry Street
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Professor Koehler S. Stout
Professor Of Mining
Montana School of Mines
Butte, Montana

Dear Mr. Stout:

The following report, Open Pit Mining Operations, is submitted in compliance with your instructions in Mining 68. The preliminary work on this report was submitted in January 1957, to fulfill the requirement in Mining 61.

This report discusses: history of open pit mining, factors important in the selection of open pit mining and in the planning of an open pit, drills, loading equipment, and transporting equipment used in an open pit, blasting, drainage and means of power supply to equipment in operation. The chart enclosed in the back cover gives data from various open pit mines.

Very truly yours,

James A. Simon
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ABSTRACT

Open pit mining is the oldest type of mining and is adapted to flat lying deposits where the amount of overburden does not prohibit this method.

Before any mining can be done, the size, grade, and tonnage of the orebody must be calculated from the exploration drill holes. Mining plans can be completed using these calculations. With the advent of better loading and drilling equipment, benches can be kept higher today than years ago. Before rotary drills came into use in the mining industry, churn drills and percussion drills were used extensively for blast hole drilling. Today more mines are using the rotary drill.

New trends in blasting is to the large diameter hole. These cut down drilling cost, secondary blasting, and the amount of explosive used. The main problem in loading is maintaining balance between the haulage and loading units so they are not idle. Shovels in use range in size up to 60 cubic yard and draglines up to 30 cubic yards. Other loading equipment being used are: front end loader, bucket wheel excavator, and power scrapers.

Many pits, which are too small to use rail haulage, are now using truck, conveyor and skip haulage. Other pits using
rail haulage are changing from steam to diesel and electric locomotives.

In those mines where drainage is a problem water is either pumped from the sump in the pit, or is allowed to drain in old underground workings. Power is mobile so it can be moved and the power source is kept as close to the place of use as possible.
INTRODUCTION

This report on open pit mining operations will discuss: the history of open pit mining, factors important in the selection of open pit mining and in the development of an open pit, and the various mining and operational methods used in this type of an operation. Stripping coal mining operations will be discussed but the majority of the report will be on open pit metal mines.

Open pit mining is applicable to flat-lying mineral deposits near the surface. Vein deposits are seldom mined by this method, although outcrops of veins sometimes are worked as open pits.

Most of the iron ore of the United States is mined from open pits. Although open pit copper mining is relatively new in comparison to other methods, more copper is mined by this method than any other type. Gold, lead, zinc, asbestos, vermiculite, borax, manganese, tungsten, barite, aluminum and many other minerals are being, or have been mined by open pit methods.
Figure 1  Partial View of Chile Exploration Company's Open Pit Copper Mine at Chuquicamata, Chile
HISTORY OF OPEN PIT MINING

Surface outcrop of ore bodies have been mined by open pit methods since the beginning of mining. In ancient days and in the early operations of this country the material was excavated by hand: later teams and scrapers were utilized.

In 1877, Hodge and Armil first used a steam shovel in the mining industry, for stripping coal in Pittsburg, Kansas, district. These operators had had experience with shovels in construction work. The first steam shovel was introduced in the iron range of Minnesota in 1893. The Utah Copper mine, in Bingham, Utah was the first of the large open pit copper mines to use steam shovels in 1906.

Operating efficiency in present day open pit iron and copper mines has improved remarkably. The tons per man-shift have been increased while costs have been lowered. These improvements were brought about by improved drilling, loading, and transportation equipment.

The old railroad-type steam shovel was the standard excavator until about 1920, when self-propelled shovels on caterpillar treads began to come into general use. Soon electric power replaced steam and gasoline, and diesel shovels were used in small operations.

Electric locomotives have replaced steam locomotives and pull longer trains than the steam locomotives of the same weight. Better tracks with heavier rails and improved hauling practices have been adopted. Trucks have proved economical in many large
scale operations where the grade is too large for rail haulage.

Belt-conveyor systems have been used as early as 1937 in a number of iron mines where there are too large a grade for rail haulage.

Improved churn drills, percussion drills, and the introduction of rotary drills into mining operations have increased drilling speeds several fold at some mines.

Prior to World War II, mining cost by many underground methods were comparable to open pit cost. But by the end of the war these conditions had changed. Underground cost had risen steadily for labor and supplies, and difficulty was experienced in finding experienced underground help. Also development was behind schedule in many places. On the other hand open pit cost has been sharply reduced through the development of modern earth-moving machines and plenty of labor was available for surface work. During this period there was a decided swing toward open pitting in the mining industry.
FACTORs INFLUENCING THE SELECTION OF OPEN PIT MINING

In flat lying deposits the principal factors to be considered in deciding between an open-cut and an underground method are relative thickness of the overburden and the ore body; size of the ore body; relative cost of mining by open pit and by an underground method applicable to the deposit; relative dilution and loss of mineral of mining by an open pit and an underground method; relative cost of development for production by the two methods; climate; snowfall; topography; continuity of projected operations; availability of skilled labor; and capital available for stripping and purchase of equipment. 1

Ratio of Overburden to Ore

Open pit operations begin with the removal of overburden over the area where mining is to be started. The mining of this overburden follows the same system as the mining of the ore. In addition to overburden, waste rock surrounding the ore body must be removed as pits attain depth, in order to provide a safe side slope in the workings; moreover, bodies of waste included in the ore must be removed at the time of mining and kept separate from the ore. The overall slope of the sides of the pit determine the amount of waste surrounding the ore, that must be removed; this in turn, is governed by the character of the rock.

In many operations the success met in removing overburden determines if a pit can be economically mined.

In determining the cost of mining a unit of ore, is added the cost of mining the waste that must be removed to get at the ore. The volume of waste mined for each volume of ore is known as the ratio of waste to ore.

There is no fixed rule regarding the amount of waste that can be removed for each ton of ore mined. Thru sound engineering practices and planning, each pit operates with as large a waste to ore ratio that is possible to maintain. When the waste to ore ratio becomes too small to economically mine by open pit methods an underground method is adapted.

In 32 mines on the Lake Superior District, 36,100,000 tons of iron were produced and 25,000,000 cubic yards of overburden and waste were removed in 1947. This gave an overall ratio of overburden to ore of 0.7 to 1.2

Size of Ore Bodies

Before the introduction of truck haulage, in the open pit mining industry, many smaller deposits had to be mined by underground methods; because the size of them made it impossible to use rail and track haulage. Railroads need low grades, and to maintain low grades the pits have to be quite large. The cost of installing rail haulage was large, so the deposit to be mined had to be large enough to pay for rail haulage.

Many relatively small ore bodies are being mined by open pit methods, since the introduction of truck haulage. These same pits could not be exploited economically using rail haulage system.

Where size of ore bodies used to be an important factor in the selection of the open pit mining method it now has less emphasis placed upon it. With the new equipment being used in open pits small as well as large pits can be mined by this method.

The Mesabi Range in northern Minnesota, about 70 miles northwest of Duluth, is the largest single source of iron ore in the United States. It is 75 miles long and ranges in width from 1-1/2 to 3 miles. The maximum thickness of this range orebody is 450 feet.

The depths of 32 open pit mines in the Lake Superior District ranged from 45 to 450 feet. Three of the mines were less than 100 feet deep, 14 were from 100 to 200 feet deep, 7 were 200 to 300 feet deep, 5 were from 300 to 400 feet deep, and 3 were 400 to 450 feet deep. The average depth was 216 feet.3

The same mines ranged from 400 to 13,000 feet in length and 400 to 4,000 feet in width. The average length was 3,150 feet and the average width 1,700 feet.

Cost of Open Pit Mining to Underground Methods

Time and money are required for the initiation of open pit operations whether larger or small. A toll is imposed upon every ton of ore exposed, by the removal of the overburden. The cost of stripping accumulates until ore can be mined. Most of the equipment and assessories in the open pit industry involve large capitol expenditures at the start of operations. In many pits the development goes on for years before any ore is actually shipped from the pit.

Operating cost in an open pit are another thing. In most open pit operations labor output in tons per man shift is large. The larger the pit, the larger the labor output. In open pit mining less skilled labor is needed than in underground methods. Also less supervisors are needed in open pit operations.

The development cost of underground mining methods is also high, but usually as development proceeds mining also can be done. Much of the cost of development can be paid by the mining that is being done. Because of this, less money is needed to get started in an underground method.

Operating cost underground are high compared to in an open pit. The tons per man shift are low and more supervisors are needed in an underground system. Added to this is the cost of maintaining the underground working, and in many places of filling mined out areas.

Operating efficiency in present open pits has improved
remarkably. Because of improved drilling, blasting, loading and transportation equipment, the tons per man shift have been increased while cost have been lowered. In contrast to this, the cost of underground mining has increased.

Where operations will not be continuous, open pit mining is decidedly advantageous. Shut down expenses are small, and the cost of getting a mine ready for production after a shut-down is much less than with underground methods. In underground methods, large blocks of ore are lost if operations are shut down long.

Ore can be mined cleanly by power shovels in open pit with little or no dilution in grade. In some instances, thin edges of the ore under extremely thick cover may be lost. In others, because of the danger of slides, it is impracticable to remove all of the ore in a bank. In most underground methods, some loss of ore and dilution is inevitable.

Topography of the Area

Topography of an area influences the selection of an open pit method. Lack of room for disposal of waste and long costly approach grades may make this method uneconomical in some instances.

Most open pits are in flat or rolling topography of moderate ascentuation; some, however, are in rugged country or on hill or mountain slopes; many have natural drainage but others become sumps. In deep mines, a big problem is the support of the enclosing walls. The thickness of the deposit and its environ-
ment of surrounding hills or ground masses and their rock character, determine how great a quantity of marginal material must be removed to secure stable slopes. This is an important item to cost as it plays an important part in figuring the ratio of overburden to tonnage of ore. If there is too much waste it might result in mining the area by another method of mining. 4

Climate

In regions of cold and heavy snowfall, an underground method has certain advantages. On the iron ranges most of the ore is shipped down the Great Lakes; transportation of this ore is stopped for about five months during the winter because of the freeze up of the lakes. Much of the ore shipped from the iron ranges is concentrating ore, and the concentrating plants must be shut down during the cold.

At most of the open pit iron mines stripping is done in the fall and winter after mining operations are finished for the season; however some places stripping is carried on year round.

Snow and cold are combated in the copper mines in the west. Sometimes there are temporary shutdown of from one to several days, but because the ore is either shipped by rail or truck the mines can keep producing.

PLANNING AN OPEN PIT

There are as many ways of planning an open pit mining operation as there are open pits. However, there are certain essentials that are common to all, certain steps that must be taken, and certain factors that apply to all successful operations. The purpose of this section is to set down those factors briefly, to give an idea of the elements of modern pit planning.5

Exploration Drilling

Rarely will the engineering department that is given the job of planning a pit, have handed to it a map of the orebody with all drill holes laid out in neat lines and limits of the orebody clearly marked. Instead, the limits of the orebody are only vaguely defined and drill holes are needed to define the orebody.

One of the first jobs, therefore, is to do enough drilling to obtain full and accurate information on tonnage and grade of the orebody and on the nature of the surrounding waste rock.6

Drilling is carried on a pre-determined grid pattern, usually on 100 to 500 foot grid pattern. Where the ore is homogeneous the drill holes can be farther apart, but where the structure is complicated, holes must be closer together.


6) Ibid, P. 63.
In some operations, holes are drilled on a regular grid pattern, when more information is needed auxiliary holes are drilled at closer intervals.

This can be done either by churn drill, diamond drill, or rotary drill, depending on depth of orebody, type of rock, structure, grade and equipment available. Diamond drilling gives the best information because by this method a core is recovered. This is also the most expensive type of drilling, therefore, where another method can give satisfactory results, it should be used. In recent years rotary drilling has been increased because of the speed with which this drilling can be done.

Geophysical Exploration

Where it is feasible, geophysical work has been found extremely helpful in supplementing or guiding drilling campaigns. If the orebody is of a nature that makes such work possible, a geophysical survey should certainly be run over the mine area in order to make sure no bets are being overlooked.

Magnetic and Gravemetric surveys have been used in developing open pits and will be used much more in the future because of the success already experienced with these methods. Seismic methods have been used but have not been very successful yet, although it is sometimes used along with a drilling program.7

Calculation of Grade and Tonnage of Ore Reserves

After completion of an adequate drilling campaign, one can calculate tonnage in various ways. There is the method of connecting all the drill holes by lines in such a way as to make triangles with the holes at their corners. The average grades of these triangles, and their areas, then make up the grade and tonnage of the orebody.

Generally preferred, however, is the polygon method in which a drill hole is taken as a center and radiating lines are drawn to the other holes surrounding it. At the centers of these lines perpendiculars are erected which, when extended, form a polygon that is assumed to be the area of influence for this particular hole. This method can be extended over the entire area of the orebody, and has been found quite reliable in calculating tonnage and grade figures.

A final method is to calculate tonnage and grade on each bench after the mining plan has been established. This can be done by planimeter on sections run at regular intervals across the orebody. Tonnage tables can be worked out so that for each grade of ore and for waste, one can read off the tonnage for each square inch of section area. 8

In calculating the total tonnage and the average grade of an orebody, after the area of influence of each hole has

been calculated, the first thing to do is find the tons of ore in the area of influence of each drill hole. This is done by the following formula.

\[
\text{Tons} = \frac{\text{Thickness (ft)} \times \text{Area (ft)}^2 \times \text{sp. gr.} \times 62.4}{2000}
\]

Total tonnage is obtained by simply adding the tonnage calculated from each individual drill hole. To calculate the average grade of an orebody, multiply the tons of ore in the area of influence of each drill hole by the average grade of each hole, which gives tons times grade. Add the tons times grade of each drill hole, and divide by the total tonnage to arrive at the average grade.

**Determining Structure**

In addition to tonnage and grade of ore and waste, the prospecting campaign should yield accurate information on geological structure. In some pits where structure is uniform and bedding is absent this is not so important, but in other orebodies where there is complicated structure, the structure is extremely important to the success or failure of the mining plan.

In one pit the orebody, a bedded deposit, was faulted and intruded by dikes. It happened that the slope of the footwall side of the orebody was about right for the final pit slope, but determining of the hanging wall slope required the most careful planning. It was also necessary to do considerable calculation to allow for various faulted blocks of ore. All this was based on careful and thorough geological work.
Planned Method of Mining

Once the exploration program has furnished an idea of tonnage, grade, and structure, the management of the mining company must come up with some major decisions on which further planning must be based.

Generally the first thing a mining company must decide is how much and what part of an orebody can be mined by open pit. Many mines have started as open pit and have gone to an underground method when their waste to ore ratio became too high. Figure 2 is a good example of this.

"An old rule-of-thumb, about as reliable as most such rules, is that the border between open pit and underground is a waste to ore ratio of 3 to 1. Actually such a decision has to be based on a comparison of cost, bearing in mind such items as: the greater tons-per-man-shift output of a pit; the greater complexity of underground mining; and many other economic factors."  

Planned Production

At this point, the management must decide upon the planned daily production that is going to be mined in this pit. Many factors enter into this but the controlling ones are: capacity of the smelter or mill to which the ore is being shipped, the amount of capital available to buy equipment with, and in many places the kind of equipment that is available, that can be used.

Many operators decide that it is cheaper to contract the stripping and just do the actual mining of ore themselves. The

Figure 2: Open pit mine that had to go underground as waste-ore ratio became too high.
point is, that a contractor can put a large investment into mining equipment, larger perhaps than the mining company could afford. The contractor can ram the stripping job through at a rate the mining company might not be able to match, unless it were prepared to take it slower on stripping, or to use all the stripping equipment in the subsequent mining operation.

Most of the iron ore pits operators have done their own stripping on contract. In general, smaller pits seem better bets for contract work, as well as those operated by companies without substantial prior experience with open pit work.

The next thing to be considered is the type of haulage to be used. The factors that determine this are simply the size of pit, and the length of haul to the waste dump or crusher. Haulage will be discussed thoroughly in another part of this report.

The next thing to be decided is the size, type and number of pieces of loading equipment. Power shovels are the main type of loading equipment used, but draglines, dredges, track mounted front end loaders, power scraper excavator-loader-transporters are also being used. These will also be discussed in another section of this report.

**Size and Height of Benches**

At one time size and height of benches was limited by the drilling depth of the drill being used, but the new advances made in the drilling field have removed such restrictions. Where power shovels are being used, shovel-digging heights are
sometime a limiting factor. Bench heights in excess of this sometimes result in overhangs, which endanger both shovel and the operator. These occur where soft material is being excavated but seldom develop in hard rock piles.

There is an economic relationship between the number of benches being used in a pit. Each bench requires tracks or roads, which must be moved as cuts are taken; and each of the benches must be drilled and blasted. The lower the bench height the more time spent on moving roads, track drill set up time, and time spent preparing to blast.

In coal mining and many other industrial mineral deposits the benches are established by the thickness of the overburden and the thickness of the deposit. In many iron pits where ore of different grades is being mined, the thickness of individual grades establish bench heights within limits of 20 to 40 feet, with 30 feet favored. In copper pits, bench heights are from 25 to 70 feet, with 50 feet favored. Benches up to 200 feet have been mined in some thick limestone deposits.

Bench widths vary from 50 to 250 feet, and the bank slopes range from 45 to 65 degrees. The harder the rock the steeper the slope that can be maintained. It is interesting to know that breaking becomes easier as mining of ore proceeds, probably because of the expansion resulting from removal of large amounts of overburden and ore. 10

Pit Approaches and Methods of Attaining Depth

In many deep deposits with thick overburden, considerable depth must be reached to mine as an open pit. Where mining is started on a hill top or along a mountain slope, the benches are reached by the switchback systems where tracks are used or by road grades where truck transportation is favored.

Switchbacks are used to gain depth without sharp turns by a series of grades requiring alternate advancing and backing of trains. Each grade is made as long as possible and ends in a track long enough to accommodate a full train. A system of switchbacks is shown in Figure 3.

Spiraling down in a pit involves a continuous grade on ore banks, thus necessarily restricting the minable area in the bottom of the pit, as greater depths are reached. When these pits are finished these banks contain considerable tonnage and must be mined by other methods. Figure 4 shows a system of spiraling down as used in many pits using truck haulage.

A flat pit site necessitates an approach with adverse grades which may be a railroad grade, an incline hoist, belt conveyor equipment, or a roadway depending on the grade required. Railroad grades are extended downward as a box or drop cut, which are just extended downgrades at low enough grade to handle rail haulage.

In many pits the ore is dropped to the bottom of the pit where it hoisted by an inclined hoist or by a belt-conveyor
Figure 3  System of gaining depth by switch backs

Figure 4  Spiraling to an open pit floor
system. This is usually done in narrow difficult pits. Where a hoist installation is used, cars are hoisted up the incline and dumped into bins on top. When conveyors are used the ore is crushed before being transported by the conveyor. This will be discussed more thoroughly in another section of this report.
DRILLING

This section on drilling will discuss the different types of drills used in open pits both for exploration and blast hole work. Several illustrations will be used in describing these drills. A later section will discuss type of drill rounds along with blasting techniques.

A number of types of drills are being offered to open pit operators today and all types are being given serious consideration or trial. The universal drill for each type of ore has not yet been invented, as some operators use as many as seven or eight types of drills and are eager to know more about new units now being developed.

The main type of drills being used in open pits and the ones we will discuss are the churn drills, rotary drills, percussion drills, and flame-piercing.

Churn Drills

The churn drill has been used since the turn of the century in the open pit industry and is still holding its own against varied new competition.

The churn drill is a variation of the American standard cable rig. It digs a vertical hole, employing a bit hung on a cable to which motion is imparted by one of various types of power units. The bit is lifted a few feet and dropped. The churning motion of the bit abrades the ground, and so a hole is dug. The cuttings form a mud or sludge which is
Figure 5  Caterpillar Mounted Churn Drill
removed from the hole at regular intervals. Drilling is accomplished by importing a rectilinear motion with a magnitude of 18 inches to 3 feet, and a speed of 30 to 60 strokes per minute, to the cable or rope on which the bit is suspended. On earlier rigs the drilling cable was attached to one end of a center pivoted walking beam actuated by a crank and rod. Power on this type of rig was supplied by a steam engine. Present models employ internal combustion or electric power, and the stroke is imparted to the drilling cable directly by a lateral pull from a crank, rod and pulley assembly. Modern churn drill rigs are usually mounted on a caterpillar tread or on a self-propelled wheels. Under normal drilling conditions a crew of two men operate the drill when it is being used for blast hole drilling.\textsuperscript{11}

Virtually all churn-drill holes use to be 6 inches, but the trend in hole size is upward, 12 inches being the present maximum. The 9 inch hole, commonly used, continues to prove the most satisfactory in drilling results. The ratio of tool-weight per inch of diameter can be increased to give faster penetration with the larger holes. Chisel-type bits (concave, convex, and straight-edge) are generally used to drill in ore.

Diesel-operated drills compare favorable with electric units. In one Arizona mine, a diesel-operated churn drill was operated 6000-7000 hours without need of repair. These are\textsuperscript{11}

Figure 6 Large Caterpillar Mounted Percussion-Type Drill
much more flexible than the electric type as there is no problem of feeding the electric cable to the drill.

In the Lake Superior District, with few exceptions, vertical blast holes are drilled with standard caterpillar mounted churn drills. In the copper open pits in the west the churn drills are still present although they have much competition from newer model pneumatic and rotary type drills.

Churn drills are used extensively for exploration drilling as well as blast hole drilling. Samples are taken from the sludge which is withdrawn from the hole. Figure 5 shows a typical caterpillar mounted churn drill that is used on the Lake Superior Iron Ranges.

Air Drills

Two types of air drills are in use - piston drills and hammer drills. Piston machines were developed first and were being used in underground mines when copper mining by steam shovel started. When air drills were desired for open pit work, large piston machines mounted on tripods were selected. Drills of this type are still being used in a few places today.

Hammer drills were first used in open pit mines for plugging boulders. This type of drill was slower in getting started in open pit mines, but, today is used extensively. Hammer drills are of two kinds, a heavy machine mounted in various ways and a smaller size called a sinker that is held unsupported
Figure 7 Medium Size Wagon Drill
in the operator's hand. In the hammer drill or percussion drill, the valve lets the air in the cylinder, the air causes the piston to strike a blow on the head of the drill rod or the tappet, which transfers the blow to the drill rod, which in turn transfers the blow to the drill bit pressed against the bottom of the hole. The sharp edges of the bit cut the rock, and the steel rebounds as the piston returns and the rotating mechanism turns the drill steel and bit to a new position. In contrast to the churn drill the force of the blow is small, but the number of blows, up to 3,000 per minute, is great. By means of the throttle and feed adjustment, the number of blows and their intensity may be varied to suit the conditions.

When hammer drills were first used in open pits, they could not be used to drill deep holes, but, with development of bigger and better drills, depths of 250 feet have been drilled.

Where small-diameter drill holes are adequate, small wagon drills are used. These drills can be used for flat as well as vertical holes and have a fairly fast drilling rate. In the last few years several manufacturers have developed large self-propelled hammer drills that produce 4 to 6 inches holes and are very maneuverable. A new self-propelled, self-

Figure 8  Self-Propelled Secondary Blasthole Percussion Drill Rig

Figure 9  Self-Propelled, Self-Contained, Self-Powered Percussion Drilling Rig
contained, self-powered drilling rig that contains its own compressor has found many uses in open pit mines. These carriages are either caterpillar or rubber tired mounted and have pneumatic drill positioning arms. With this type of drill, flat toe holes can be drilled easily and it can also be used for drilling secondary blast holes. Figure 6 to 9 show different types of hammer drills in use in open pit operations.

Among the new drills most talked about today is the high-frequency percussion drill (of the order of 300 cycles per second) which is being developed by Drilling Research Inc., a non-profit organization, by some 40 oil companies. The rapid increase in the use of large percussion drills (bit size 3-1/2 to 6-1/2 inches) can definitely be attributed to the development of tungsten carbide for bits.13

**Rotary Drilling**

Although rotary drilling for open pit blast holes is gaining widespread adoption, it is just recently that it has been used in this respect. Drill manufacturers feel certain that deep hole drilling will eventually involve rotary units and in-the-hole drills which eliminate the necessity of transmitting shock by percussion through long sections of steel.

In rotary drilling the cutting is accomplished by pressure and relatively high-speed rotation of the bit or cutting head,

Air is used to expel the cuttings and to cool the bit when using rotary drilling in blast hole work.

The Utah Construction Company is using a Joy 58-BH Heavyweight Champion Rotary Drill weighing about 48,500 lbs. It is powered by a 50-hp electric motor, the compressor rated at 554 cfm powered by a 125-hp motor, and a centrifugal type dust collector powered by a 5-hp motor. This drilling machine is self-propelled on crawler tracks and drills dry. The mast is designed to handle a 40 ft drill stem.

Prior to delivery of the new machine at the Cedar City, Utah, open pit iron mining and stripping operation, blast hole drilling was done with wagon drills. Wagon drilling required 6 to 10 drills, depending on the material to maintain adequate muck for each 6 cubic yard shovel. This one rotary drill is able to produce enough volume to keep ahead of one 6 cubic yard shovel.

The original Joy drill shows approximately 4,000,000 cubic yards of overburden drilled, consisting of limestone, sandstone, caliche and quartzite. The overall drilling speed has averaged 41.2 feet per shift using a 7-3/8" bit.14


Figure 10  Caterpillar Mounted Rotary Drill
These drills are sinking an average of 129 feet per shift of 12-1/4 inch blast hole, which is a considerable gain over the 39 feet per shift of 9 inch holes drilled by each of the churn drills formerly used. Furthermore, 6 men using the 50-B now do the job formerly done by 25 men.15

At the Berkeley Pit in Butte, Montana, F and S Construction Company has 2 medium-size rotary drills capable of exerting 50,000 pounds pressure on the bit. These rigs are mounted on crawlers and contain their own power plants. They are equipped with a mast which provides a ground to sheave height of 47 feet 8 inches. A third unit is also employed which is a truck mounted rig that is normally used in ore since it is smaller and more mobile. It has a 40 foot mast plus a hydraulically operated automatic chuck. The large drills use 9 inch diameter tricone bits and the truck mounted drill uses a 6-1/4 inch bit. Actual drill footage over a month's time will average 650 feet of hole per drill shift.16

Rotary drills equipped with a dust collector to catch the cuttings are being used more and more for exploration drilling. The cuttings are used for a sample and very good results are obtained. Figure 10 and 11 show good examples of the types of rotary drills being used in today's open pits.


Figure 11 Truck-Mounted Rotary Drill

Figure 12 Flame-Piercing Rig Used For Drilling in Taconite
Diamond Drills

Diamond drills are used very little for blast hole drilling although they are used in many places for exploration drilling. Diamond drilling is the most expensive drilling method and is therefore, passed over when other drills will do the job.

In diamond drilling, a ring-like bit, armed with small diamonds, rotates and cuts out a cylindrical core of the rock through which it passes. The bit is mounted on the end of a shaft consisting of hollow flush jointed rods. The rods convey motion and pressure from the drilling machine to the bit and also serve as a pipe to conduct a stream of water which flushes away the cuttings and ground up rock. The ore is pulled by a wire line core barrel which drops down inside the rods and clamps on to the core.

When diamond drills are used for blast hole drilling, they use a solid bit and no core is recovered. This is cheaper than core drilling but still expensive.

Flame Piercing

As footage and experience increase confidence in flame piercing grows in possibilities of this method for breaking taconite. The JPN-1 Rig, on Erie Mining Co.'s ground, recently made 156 feet of 6-1/2 inch hole in an 8 hour shift. Cheaper oxygen and lower charges in general will improve flame-piercings competitive position. Kerosene consumed in
flame piercing is reported to be about 22 lbs. per foot of hole. Figure 12 shows the type of rig used for this.17

**Auger Type Drills**

For large-diameter horizontal holes, the McCarty rock-boring machine has proved of value. It is used at a small eastern Mesabi pit with 6 inch coal auger and a 6-1/2 inch carbide tipped three pronged auger bit, broke up the soft ore bed and the overlying hard taconite capping, so that the latter could be sorted out by shovel.

As 6 mines on the Mesabi Range, gasoline-driven drills with 6 inch diameter rotating augers were used, and at one mine, a compressed-air driven drill with a 3-1/4 inch auger was used.18


BLASTING

There are almost as many different methods of blasting in open pit, as there are open pits, although two major methods are used; vertical holes drilled from the top of the bench and toe holes drilled flat or nearly flat along the toe of the benches.

The spacing of hole is never the same for two separate ore bodies, and often is never the same in one ore body. Hole spacing depends upon the hardness of the ore, the expected fragmentation and the amount and kind of powder used. Vertical holes are usually drilled from one to four feet below grade, to assure clean break and permit maintenance of a smooth road bed at proper elevation. In pits using truck haulage, this cuts haulage cost considerable, as the chief expense is from tires and tubes.

There are many variations of bank blasting, but only two major practices are followed. One involves occasional blasting of many drill holes in a major blast with resultant tonnage to ensure a long period of loading operations; the other requires the periodic blasting of sufficient drill holes in a group to ensure steady loading operations over short periods.19

Trouble from overhangs is avoided by distributing charges

with some of the explosive placed near the top of the hole. Secondary blasting has been reduced in amount by the use of large-size crushers, shovels, and better fragmentation by the use of higher power explosives. This does not mean there is not secondary blasting being done as secondary blasting is necessary in every open pit where blasting is being practiced. Figure 8 shows a self-propelled drill rig used for secondary blasting in many open pits today.

Blasting results with larger diameter holes has proved successful and has cut drilling cost appreciably. Using large holes, the toe is well broken and the fragmentation in general is better than with smaller holes. Less heave results, and the broken material usually stays within the boundaries of the bench. Fewer holes, larger in diameter, have meant that powder and stemming are more easily introduced and the holes loaded more rapidly. Less secondary drilling is required and therefore, less powder is used. 20

Spring Holes

Chamber blasting or springing is being rapidly superseded by larger diameter holes using column blasting. Springing consists of blasting a charge of four to fifteen pounds of dynamite in the bottom of the hole before the main charge is loaded. In some places, this is done up to six times before

20) Parker, John, L., "Blasting Santa Rita Copper, Excavating Engineer, Vol. 43, pp. 13-14, October 1949."
blasting the main charge.

Springing involves definite hazards from premature explosions, during placing of the springing charges or the final charge, due chiefly to heating of the bottom of the holes by the successive exploding of the springing charges. This danger is sometimes unknown, or disregarded in many instances and is responsible for many accidents in open pit and quarry work. This heat is introduced into the hole because dynamite develops temperatures as high as 6,000°F; consequently the surrounding rock is highly heated. Successive charges in the same hole tend to raise the temperature of the rock. Some explosives cause the paper wrappings to ignite and burn more or less slowly. The final result is that the temperature of the rocks and air in the bottom of a spring hole, may be high enough to ignite the explosive charged after springing.

The safest method of spring holes appears to be to pour water into the holes after each blast to cool the air, rock, and other surface and to extinguish any burning paper or other material in the hole. Where water is not used, the holes are cooled with compressed air; then a definite period (at least 2 hours) is elapsed before further loading is done.

It is better, however, to wait 24 hours, and so the system of springing holes one day and blasting them the next is
followed wherever feasible. 21

Loading Vertical Holes

The first thing to be done before loading of any holes is to check and see that it is not obstructed. If it is obstructed, they are cleaned by redrilling or by shooting with one or two sticks of dynamite.

Usually in wet holes, semi-gelatin dynamites, gelatin dynamites, or a blasting agent in sealed metal cans are used. In dry holes ammonia dynamos in cartridges and bags are used. At most mines, powder cartridges are dropped into the hole, except where holes are ragged or else when blasting agent is being used. Then the blasting agent is lowered into the hole. At most mines cartridges of explosives are tamped when it is put in the hole; however, at some mines, the charges are not tamped or are tamped after every second or third cartridge. Primers are not tamped.

The general practice is to lower primers with detonating fuse into the hole, with the fuse supporting the weight. Position of the primer varies from mine to mine and can be anywhere in the charge of explosive at one mine, 2 primers are used in holes 40 feet deep; one primer is placed 3/4 of the distance to the bottom of the charge and the second is placed at the center of it.

When loading vertical holes, the detonating fuse is cut off about 3 feet above the collar of the hole. At some mines the fuse is cut off immediately after the primer was lowered into the hole (safest method), and at other mines it is cut off after the entire charge of dynamite is loaded into the hole.

Loading vertical holes promptly after drilling prevents the hole from becoming blocked. This is not considered a dangerous practice when using detonating fuse, because no detonator is in contact with either the explosives or the fuse until immediately before the blast.22

**Stemming**

For stemming material, virtually all the mines use fine ore obtained at the blasting site. The stemming material is shoveled into the hole and very seldom tamped. The holes usually are stemmed to their collar, although, deck loading is sometimes used. This is just stemming on top of the main charge, and then loading another charge on top of the lower stemming near the middle of the hole. Then the hole is stemmed to the collar. This is used to eliminate overhangs in some mines bothered by this trouble.23


Loading Horizontal Holes

In horizontal holes, the dynamite cartridges or bags are pushed into place and tamped separately. At some mines wooden troughs are provided to facilitate loading the dynamite into rough holes. All holes are stemmed to the collar and the stemming fills about half of the hole. The primer cartridge is usually placed at the bottom of the hole, although, it can be placed elsewhere.

Quantity of Explosives Used

Iron ore in most open pit mines is blasted primarily to loosen the material for the power shovels rather than to dislodge it; consequently, loading the holes with heavy charges of explosives is not necessary. In hard ore mines like the copper mines, heavy charges are used.

In some mines the quantity of explosives to be used per hole is left to the judgement of the blaster, who learned from experience, how much is necessary to break the ground for efficient shovel loading. At other mines, however, the burden on each hole is computed, and a pre-determined factor is used.

Connecting Blast Holes

Plain detonating fuse is generally used for trunk lines to connect several blast holes. The branch line of fuse from each drill hole is tied at right angles to the trunk line with a half hitch, so that the loose end does not point toward either the branch line or the trunk line. All connections
are counted and inspected before attaching the detonator to the detonating fuse. Common practice is to secure the blasting cap or electric detonator to the end of the fuse with friction tape.

When 2 rows of holes are connected to a single trunk line, the detonating fuse is laid along the front row of holes and looped back to lay along the back row of holes. The free end of the trunk line is then connected to the main part of the trunk line between the detonator and the first hole in the front row, thus forming a closed circuit and permitting the detonating wave to travel along both the front and back rows of holes simultaneously. Two or three parallel rows of holes frequently are blasted separate to reduce the violence of the blast. A trunk line is used for each row of holes, and electric detonators of the proper delays are used to detonate each row at desired intervals.

Generally, 14 or 16 gauge duplex wire is used for blasting lines between the electric detonators and the power circuit or blasting machine; although, copper wire is sometimes used. The general practice is to keep the ends of the blasting lines shunted until they are connected to the source of power, but this is not always done. At some mines the blasting circuits are tested with a galvanometer to insure that the circuit is continuous and in proper firing condition.
Secondary Blasting

Secondary blasting is still required at most open pit mines, although it is not required as much as before. Some mines use block-holing while others practice mud-capping for their secondary blasting. For hard boulders, holes must be drilled, either by hand held drills or by mobile self propelled drills. These holes are drilled from 10 inches to 2 feet depending on the size of the boulder. These holes are loaded with 1-1/4 by 8 inch cartridges of dynamite. If many holes are being blasted, each charge is connected to a detonating fuse trunk line and detonated with a single electric detonator. If only a few charges are being blasted or if the charges are to close together, each charge is primed with an instantaneous electric detonator, and the group of shots are connected in series and fired.

Mud-capping charges range in size from 1/2 a pound to 50 pounds of dynamite, depending on the size of the chunk or boulder. These charges are detonated either by cap and fuse or by detonating fuse.

Milliseconds Timing

Recently, explosives manufactures have developed fast delay or millisecond-electric blasting caps that fire individually, but in such small difference in time relation to each other, that the action of certain charges supplements the action of other charges before there has been any appre-
ciable movement of the burden or release of gases from behind the burden.

Although these are little used in the open pit iron mines, they are being used in quite a few of the open pit copper mines with very good success.
EXCAVATING EQUIPMENT

From the time the blast is detonated, open pit mining becomes only another form of earthmoving, which is itself a special form of materials handling. In handling bulk materials, one tries to do the job smoothly, mechanically, in conveniently-handled units, with a minimum of lost time, and at an optimum rate, depending on the size of the completed job.

Of course loading comes first in doing the job, but it also comes first in the planning. Once the size and the number of excavators are determined, the size, number, and scheduling of the haulage units can be fixed.

The large pits will simply use the required number of shovels of the largest capacity they can afford that will dig the necessary daily tonnage. Actually there are a number of considerations, that will be discussed farther in this paper.

There is gradually growing in the industry, an awareness of the fact that open pit mining is not as simple as it may look to the outsider. First, there are obvious elements of proper scheduling of digging on the various benches so that an adequate supply of ore can be maintained. This means planning far enough ahead to keep stripping well in advance of ore production. Next, there are the less obvious elements such as keeping the right balance between haulage and loading units so that each can work to fullest capacity. Idle time, for even a few minutes between trips, means wasted capital
and labor cost, and lost production. Last, there is the final refinement of seeking out the optimum digging arrangement that will give the most production at the least expense.

All one can say at present is that with larger units now coming into use, both in loading and haulage, it becomes imperative that these units be used with even greater efficiency than has heretofore been thought satisfactory.\(^{24}\)

The method of excavation and the selection of mechanical appliances are determined by the nature of the material, the topography and general conditions, the quantity to be handled, and the capital that is available. Excavating appliances that will be discussed are shovels, draglines, bucket excavators, front end loaders, and the hydraulic methods.

**Power Shovels**

The first shovel was used in the mining industry in 1877 for coal stripping. From then until 1920, the railroad type steam shovel was the standard excavator. Since that time modern engineering has made many improvements in the power shovels until now, improved shovels are in use on many different types of jobs.

The modern power shovel is full-revolving, mounted on tread tractors and operated by electric motors, diesel engine, or gas engine. It is a mobile unit moving under its own power.

and handled by one operator. Its principle motions are the swing around its axis, the thrust of the dipper as it takes its load, the lifting action of the dipper, the swing into dump position and the opening of the dipper door. The dipper is provided with a cutting edge and with teeth for tearing and cutting into the bank and for handling coarse rock.²⁵

Shovels range in size from 3/8 cubic yard capacity, which are used in small clay and industrial mineral deposits, to 60 cubic yard capacity shovels, which are used in coal stripping operations.

Shovel capacity depends upon material handled and bank, loading and transportation conditions. The present tendency in design is to increase power relative to dipper size, thus giving greater speed in swinging, crowding, and hoisting. The harder the digging, the smaller the bucket that is used.

The outstanding new trend in open pit mining and coal stripping is toward the development of large capacity shovels to remove high overburdens which were once impossible to attack economically with existing equipment. An example of this development is a newly built 60 cubic yard shovel that can handle overburdens of over 100 feet. Even with this machine, the thought of the manufacturer and operator is to increase the bucket capacity after enough experience has been gained. Previous to this year, the largest operating shovels

Figure 13 Large Power Shovel Used in Coal Stripping
were around 45 cubic yard, and it has been publicized that a shovel of 70 cubic yard capacity is now being designed and will soon be built. Tremendous reserves are now being added and made available as a result of these remarkable developments. Figure 13 shows the world's largest shovel stripping overburden from a coal seam.26 Table 1 gives the working dimension of some medium and large power shovels.

In Anaconda's Berkeley Pit, three 6 yard shovels with a maximum cutting height of 36 to 37 feet are being used. The 6 yard shovels and the entire open pit team have done an outstanding job of compiling an enviable record of over 8,000 tons loaded per shovel shift. Shovels work normal to the bench face so that trucks can be loaded on both sides of the shovel and the necessary swing is reduced; no time is lost while spotting an empty truck in position.27

To muck out the extremely heavy, and abrasive taconite, Reserve Mining Company has found that best results were obtained by using a large capacity electric power shovel with a smaller capacity bucket. As a result, eight cubic yard shovels with five cubic yard buckets are being used. Reserve has eight of these shovels presently in operation. Past


### TABLE ONE

**WORKING DIMENSIONS OF SOME MEDIUM AND LARGE POWER SHOVELS**

(All Dimensions In Feet except where specified otherwise)

<table>
<thead>
<tr>
<th>Dipper Capacity, Cu. Yd.</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>7</th>
<th>10</th>
<th>18</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boom Angle, Degrees</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>45</td>
<td>49</td>
</tr>
<tr>
<td>Boom Length</td>
<td>28</td>
<td>35</td>
<td>38</td>
<td>38</td>
<td>40</td>
<td>105</td>
<td>120</td>
</tr>
<tr>
<td>Dipper Handle Length</td>
<td>20</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>25</td>
<td>69</td>
<td>79</td>
</tr>
<tr>
<td>Dumping Height, Max.</td>
<td>21</td>
<td>24</td>
<td>23</td>
<td>25</td>
<td>31</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td>Cutting Radius, Max. Ht.</td>
<td>36</td>
<td>39</td>
<td>45</td>
<td>44</td>
<td>48</td>
<td>112</td>
<td>120</td>
</tr>
<tr>
<td>Cutting Height, Max.</td>
<td>32</td>
<td>37</td>
<td>35</td>
<td>37</td>
<td>46</td>
<td>92</td>
<td>107</td>
</tr>
<tr>
<td>Dumping Radius, Max.</td>
<td>37</td>
<td>43</td>
<td>47</td>
<td>48</td>
<td>56</td>
<td>120</td>
<td>131</td>
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<tr>
<td>Cutting Depth Below Grade</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Radius of Cleanup</td>
<td>24</td>
<td>26</td>
<td>30</td>
<td>30</td>
<td>37</td>
<td>69</td>
<td>71</td>
</tr>
</tbody>
</table>
experience with larger buckets showed that maintenance cost on shovels were abnormally high, and some mucking speed was sacrificed. Excessive maintenance cost were also realized with lighter shovel units, due to the extreme weight of the taconite.

28

Draglines

The dragline was first patented in 1904 by John W. Dage. In 1906, the full revolving steel frame and boom dragline was brought out and in 1912 the first walking dragline was produced. Since 1912, the dragline has been improved and now are run by either electricity, diesel, or by gasoline engines.

The dragline boom is mounted on a heavy steel frame that can be rotated 360 degrees and the boom angle can be adjusted to digging conditions. The bucket is operated by two lines, one for hoisting and the other for pulling the bucket into its cut and loading it. The bucket is dumped by slacking off on pull line. The revolving frame is mounted on a large steel drum that gives stability. The walking arrangement consists of steel pads or shoes on the side of the revolving frame. These pads are connected to vertical frames operated by large-throw cranks carried by a shaft rotated by a large diameter gear wheel.

Buckets vary in weight to suit digging conditions;

heavier buckets with the weight concentrated close to the cutting are required for hard as well as easy digging. Tough manganese steel is used for teeth, cutting edges, and bucket bottoms and sides.

The dragline is a versatile machine. It will dig non-coherent and well-fragmented blasted material, but not coarsely broken or compact materials. Its digging range is 100 feet below the fairlead and 50 feet above it. It is a high stacker, depending upon the length and inclination of the boom. It will excavate below water. While short-boom draglines are used for loaders, long-boom draglines are used in coal stripping, overburden excavation in soils, sand, glacial drift, and gravels.

Because the design of draglines is similar to power shovels, a power shovel can be converted to a dragline quite easily. Most power shovel manufacturers also manufacture draglines.

Draglines work well on deep cuts and soft material. Modern draglines with boom of more than 200 feet and buckets up to 30 yard capacity or even larger can dig cuts below 100 feet. A dragline hoisting function saved the M. H. Hanna Company a 1000 foot haul up a 10 percent grade in just one instance.

At the South Agnew Mine near Hibbing, Minnesota, a model 1150 B Bucyrus-Erie Dragline equipped with a 180 foot boom
### TABLE TWO

**WORKING DIMENSIONS OF SOME MEDIUM AND LARGE DRAGLINES**

(All dimensions in feet except where otherwise specified)

<table>
<thead>
<tr>
<th>Bucket Size Cu. Yd.</th>
<th>$\frac{2}{4}$</th>
<th>3</th>
<th>$3\frac{1}{4}$</th>
<th>$3\frac{3}{4}$</th>
<th>4</th>
<th>$4\frac{1}{2}$</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boom Length</strong></td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>100</td>
<td>100</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td><strong>Boom Angle Degrees</strong></td>
<td>32</td>
<td>37</td>
<td>41</td>
<td>39</td>
<td>43</td>
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and a 25 yard bucket, is used to strip glacial drift ranging in depth from 80 to 175 feet, and containing large boulders. Using this dragline there is an average output of 1000 cubic yards per hour. This represents a savings of from 30 - 50 percent over conventional shovel operation.29 Figure 14 shows a large dragline in operation.

Bucket Wheel Excavators

Bucket wheel excavators are in use in Germany, Australia, Northern Rhodesia, Belgium Congo, Italy, Yugoslavia, France, Belgium, Indonesia, South Africa and to a limited extent in the United States. Bucket wheel excavators offer unusual possibilities for low excavation and operating cost. In South Africa, one company that had been using German bucket wheel excavators since 1928 purchased cable way excavators and American scrapping equipment after the war. Operating cost of the new equipment was double the cost of the old bucket wheel excavator and the company returned to the old method.

In Germany, bucket wheel excavators are used in easy digging sand, gravel, shale, and clays overlying coal deposits. Coal up to 200 feet thick and overburden up to 600 feet thick are being mined almost entirely by bucket wheel excavators.

Since they were first extensively used during the 1930's, bucket wheel excavators have undergone rapid development, especially in the past ten years. They are simple, rigged, and offer high output for their weight. Their continuous digging action causes less stress and results in lower maintenance and power cost than are achieved with shovels and draglines. Machines are available with capacities from 180 to 10,000 cubic yards per hour. Digging heights range up to 230 feet and some machines are designed to dig very impressive depths below the level of their tracks. Digging widths are as great as 328 feet.

Development and rapidly expanding use of the bucket wheel excavators have caused many problems which had to be solved. A modified three-point suspension has given stability and self-equalization to the crawler undercarriage. The bucket wheel drive is a planetary gear train inside the bucket wheel itself, arranged to give three speeds, all with the same torque, selected from the control panel while the machine is in operation. Speed change is effected by an auxiliary motor driving a differential gear in the same direction as the main drive, or in an opposite direction. The drive is protected from shock loads by non-friction overload clutches which may be reset from the operator's cab.

The changing center of gravity, resulting from movements of the bucket wheel and discharge conveyor from side to side, is automatically compensated by a simple movable counterweight.
Figure 15 Large Bucket Wheel Excavator
The bucket wheels without cells or interval chutes used on the American machines and trenchers, are adopted especially for wheels of smaller diameter and for those required to dig below their operating levels.

These wheels without cells make possible more bucket discharge per minute and permit the buckets to be reversed for downward digging. Figure 15 shows a bucket wheel excavator discharging directly into railroad cars.

Power Drawn Wheeled Scrapers

The Letourneau Carryall, a four wheel rubber tired scraper was the first power scraper to appear and revolutionized shallow excavation in the ground. Following the Letourneau scraper many other similar units have appeared. These scraper units have found application in stripping operations and are efficient diggers in sand, alluvial, and the softer hard pan and shales. These scrapers are either powered by their own motor and pushed with a cat while loading or are pulled by a caterpillar and called tractor-scrapers.

The scraper skims its load, forcing it into the bowl, which is lifted clear of the ground and then transported to the place of disposal, unloading being done by a moveable tailgate. The success of this unit lies in its rapid loading. One advantage of this type unit is that it is both a

Figure 16 Power Scrappers Stripping Overburden

Figure 17 Track Mounted Front End Loader
loading and a **transporting unit**. Figure 16 shows a fleet of tractor scrapers stripping soft overburden.

**Front End Loader and Bulldozers**

A bulldozer is used for many things around an open pit. It is mainly used to keep the road clear so trucks can gain access to the loading equipment. It clears, spills and pushes scatter rock into the main pile. In small operations it is used to move overburden and by means of a ramp can be used as a loader.

Attachments have been devised that convert bulldozers into front end loaders and new front end loaders have been modeled after these. These front end loaders are good on small jobs where the fragmentation is good. By using a small front end loader, a shovel and a bulldozer can usually be released to be used on another job. Figure 17 shows a front end loader loading directly into railroad cars.

**Hydraulic Methods**

Hydraulic methods of excavation are methods of moving ground by means of a stream of water under high pressure. This has been used in coal stripping, non-metallic mineral stripping, and phosphate mining.

Hydraulic methods are broken down into two main groups, (1) Free hydraulicting, and (2) ejector methods. Free hydraulicting is the term used to describe a hydraulic operation
from which the tailings will flow by gravity to an acceptable disposal area. The ejector method came into use when it became impossible to dispose of the tailing by gravity flow. This is just a means of pumping the water and solid from one area to another. The ejector method is not very efficient and is seldom used.  

TRANSPORTATION

New developments such as larger trucks and better conveyors, are giving operators a much better choice than there used to be in the selection of haulage equipment. However, there are still many factors that limit one's choice.

Once the pit size is known, the grade for the haulage-way can be determined. Often the degree of slope is the critical factor in the selection of a haulage system. Other factors which are considered are the length of haul and the requirements for mobility imposed by very irregular surface of orebodies.

Generally, long hauls, large tonnage, and flat slopes tend to favor rail haulage. Short hauls, lower tonnages, and steeper grades favor trucks or belts. It has been shown however, that truck and conveyor belt combinations can prove competitive with rail under special conditions and if used right.

"Whatever type of haulage selected, it must be remembered that the excavator is the prime mover in the operation. The shovel must be kept digging, and it must be kept digging most efficiently. This means that the haulage method must not keep the shovel waiting; it must be one that takes the material dug by the shovel away smoothly and uninterruptedly."32

The haulage units must not be too few or too small in size of the shovel. There must be enough extra units so a breakdown will not cause the shovel to be idle. The haulage units must be capable of being loaded by the shovel with a minimum of swing to spot the dipper. It is important here to consider the target the shovel operator has to hit. A large haulage unit may in itself result in 15 percent to 20 percent better production than would be obtained with haulage units that present a small target.

It must be remembered that unless you are prepared to buy several large trucks, bigness is not necessarily good. The penalty for securing the benefits of extreme bigness in capacity is that such units must be more closely and carefully scheduled than small units, or operating time will be lost. That can be very expensive on large haulage equipment.

Care in spotting the haulage unit pays off in the long run. A good spotter will more than pay for his services in extra yardage. Most truck pits use two spotters so that an empty truck is ready on the other side of the shovel when the full one pulls away. Figure 18 shows a chart useful in the selection of the haulage unit in an open pit.33

Figure 18 - Chart to be used in the selection of a haulage unit.
Rail Haulage

Rail haulage will be discussed under the following headings; locomotives, cars, and track.

Locomotives

Steam locomotives were used in the beginning at all copper mines and all iron mines employing rail haulage. These old steam locomotives are not considered anymore when equipping a new mine. With the large production coming out of our iron and copper mines the choice would be between the trolley-type electric, the diesel and the diesel electric. Most large mines made the change from steam to other type either just before or just after World War II.

Electric haulage has many obvious advantages over steam. The cost of operation is considerably less, and electric locomotives can negotiate steeper grades and haul longer trains faster than can comparable steam locomotives; an electric locomotive has a higher rate of acceleration, can start a heavier load than steam locomotive. The new type locomotives have a more flexible running gear than the older type and can negotiate rougher tracks. In electric locomotives no energy is consumed while cars are standing idle. The disadvantage of the electric locomotive is the inconvenience of trolley lines on working benches.

It is considered that the cost of maintaining electric locomotives is 75 percent as much as for steam locomotives;
that a 75 ton electric locomotive will pull six 75 ton cars up a 2 percent grade at 10 miles per hour compared to five cars at 5 miles per hour with a steam locomotive of the same size.34

Diesel-electric engines are about as powerful as trolley-type engines and require no trolley system. They are more costly than the electric and need a separate power plant on each unit. Where adequate power plants are not available, or where electricity cost is high diesels can compete with electric locomotives.

In one open pit copper mine, diesels replaced the old steam locomotives in 1948. The efficiency of this type haulage is reflected in a 25 percent reduction in operating labor cost, a fuel savings of 60 percent, and a maintenance decrease of 50 percent. In the same pit additional savings were noted in less frequent derailments, easier relamlents, and less damage as a result of derailments. The smoke nuisance, ever present with steamers, is eliminated and this is appreciated greatly both by pit employees and local inhabitants.

At this copper pit, 1500 horsepower diesels are used as the "work horses" and haul eight car ore trains to the ore yard at a speed of 12 miles per hour. Small 70 ton locomotives are used to spot cars at the shovel and for hauling waste cars to the waste dump.

Figure 19  Open Pit Using Diesel Haulage

Figure 20  Dump Car Used in a Utah Mine
Engineers at this pit readily adapted themselves to the operation of the diesel units and early prejudices have disappeared completely. So far no damage to the electrical equipment has been detected than could have been attributed to engine operators. Slipping of wheels—common to both steam and diesel locomotives—is pretty well handled by the operators after a few experiences.35

Cars

Hopper-bottom ore cars from 50 to 75 short tons are used on the iron range. The ore on the whole breaks into small fragments, and because of the early end to the shipping season little difficulty is experienced from ore freezing in cars. At open pit copper mines side-dump flat-bottom cars with a 80 to 100 ton capacity are being used.

The first dump cars used were of the common contractor woodbody type and held about 6 cubic yards; since then, the size and sturdiness of the dump cars have been improved constantly. These dump cars are used for waste and usually have to withstand greater shock than do the ore cars. Any fragment that can be loaded can be disposed of on a waste dump; boulders up to 12 ton are handled by these cars at the open pit copper mines. In unloading a modern dump car, the side drops; boulders, therefore, do not catch the car when dumping and pull the car off the track. Figure 20 shows a dump car in use at Bingham.

Tracks

Tracks at the open pit copper mines and almost all of the iron mines are standard gauge. Standing railway practices are followed for all permanent and semi-permanent track at the mines; regular railway switches, frogs and track accessories are employed. As heavier equipment has come into use, heavier rails have become necessary. Where two weights of rails are used replacements generally are of the heavier type.

A large percent of labor at open pit mines using locomotive haulage is used on the tracks. Tracks were laid, lined, moved and ballasted, and the grade was prepared by hand during the early days of open pit mining, but at present, hand labor has been reduced to a minimum.

Temporary tracks at the iron mines are made up in 33 foot panels - the length of a pair of rails. New tracks are laid one panel at a time by a locomotive crane. The rails are staggered a distance equal to the spacing of two ties. The panels are carried on a flat car next to the crane and are moved by the crane a section at a time. The rails of track at the copper mines are staggered half the length of the rail on permanent track. Cranes are used for handling rails and taking up track at the copper mines. Tracks are shifted by mechanical track shifters and bulldozers are used for preparing the grades at most mines.

Permanent and semi-permanent tracks at most of the iron mines are ballasted with fine material from the pits. Tracks
on benches are not ballasted at the copper mines. Air tamping machines are used at many iron mines, but are not in general use in the copper mines.

**Truck Haulage**

During the years just before and just after World War II, truck haulage came into general use in the open pit mining industry. Trucks are much more efficient than locomotive haulage for short hauls and can now compete with locomotives on long hauls by using a truck-conveyor belt combination.

Loads can be trucked up much larger grades than the maximum grade for rail haulage. In addition, trucks can negotiate curves not passable for locomotives. Approaches outside the pit limit seldom are required for truck roads. Although truck roads can be built more cheaply per unit distance than railroads, the cost of upkeep for roads is higher than tracks. Good roads free of loose material are essential for heavy trucking, otherwise, the wear on tires and cost of repairs are excessive.

Trucks have a disadvantage in wet weather. Most open pit copper mines are in an arid region, and the nature of the ground is such that storms do not stop work. Trucking in some of the open pit iron mines is suspended during rainstorms and for a few hours after. Trucks have an obvious advantage at mines where a relative small tonnage is to be moved. The dividing point in each instance depends on conditions at the individual mines.
Many mines are now being mined by truck haulage, that could never have been mined economically using rail haulage. Many small ore bodies that did not warrant the expense of rail equipment are now being mined using truck haulage.

Trucks used for transporting ore and waste have rated capacities ranging from 2 to 70 tons and these trucks usually carry more than their rated capacity. Gasoline and diesel trucks have been used for haulage, but the more expensive diesel trucks are employed most because of the advantage of economy of operation.36

End-dumping, side-dumping, and bottom-dumping trucks are available. Truck bodies are made of steel, usually high-tensile, and weight is reduced by careful design. Dumping is done by a hydraulic cylinder and ram, but where trucks are dumped at a fixed place an auxiliary hoist placed above the dumping position is sometimes used. End-dumping bodies are made scoop shape to avoid end gates which always catch the large boulders. Trucks are specially design and built for heavy service and abuse as special trucks are the only ones that will survive large scale open pit mining.

An interesting development in box design is the application of a 1 inch bottom plate rather than a 1/2 inch plate formerly used. This substantially prolongs the life of the box.

bottom and eliminates the need for additional liners or wear bars. When delivered for cold weather operations, most truck boxes are now equipped with box heating facilities as standard equipment. Extensive experiments continue with regard to off-the-highway- tires. A number of mining companies are operating tubeless tires with highly satisfactory results. Since a high percent of mine truck tire troubles stem from tube failures, elimination of the tube should prove beneficial.

New truck types have appeared in the field, and although most mines employ single axle or tandem axle rear dump trucks, there are several interesting truck-trailer combinations in use. Most of these have high powered engines and large capacity boxes. Figures 21 and 22 show examples of the types of trucks used in open pit mining operations.

Belt Conveyors

Along with the advances in truck haulage in open pit mines came the introduction of belts to convey the ore out of the pit, and motor trucks, tractors, and wagons, or tower excavators to assemble the ore for loading onto the conveyor belts. With successful installation of belt conveyors for this purpose, many operators are considering changing from locomotives to belt and truck haulage. Many pits which formerly could not be mined can now be mined economically using this method. This method eliminates railway tracks, locomotives, and wheelwrights. However, the amount of maintenance for the conveyor system is greater. Many operators are still using both methods since the belt conveyor system is not economical for all their needs. Many of the early attempts at using belt conveyors were not successful. Many were not able to convey the ore from the mine face to the tipple at the proper rate. This sometimes resulted in tying up valuable power in the belt system, and created other problems. The belt conveyor has shown itself to be an efficient, reliable method of moving the ore and is being used with increasing frequency in many open pit mines.

Figure 21  End Dump Truck

Figure 22  Bottom Dump Truck
tives and cars from the pit itself, and with this a large percent of the manual labor carried on in the pit. In many pits, using other types of transportation, deep areas and otherwise inaccessible areas are mined using conveyor belts.

Many open pit mines, and strip coal mines using draglines, use conveyor belts as their complete haulage unit. In this system, the rock is loaded into a portable hopper which feeds the conveyor belt servicing the loading equipment. If large boulders are a problem, a combination hopper and screen is used before the rock is loaded onto the belt. Bucket wheel excavators can also be used in combination with belt haulage and the need for the loader and hopper is eliminated. Figure 23 shows a dragline loading into a hopper which is used to charge a conveyor belt.38

The belts are giving satisfactory service and are said to be preferred to trucks for transporting ore out of the pit at the mines where they are used. The difficulty experienced from ore sticking to the belt is overcome when the belts were cleaned by spraying with water under pressure. This method cannot be used in cold weather because of the growth of ice on the belt and pulleys. When ore is fed to the conveyor properly, no time is lost and life of the belts is long, but if the belt is feed too fast, or to rough the belts

are shut down for repairs and life of belts is short.

A railway yard for loading cars and assembling ore trains is situated adjacent to the rim of each pit using belt conveyor systems, as just the internal system of haulage. If belts are used in stripping operations, the belts usually discharge their load in the dump area.

The belt conveyor system not only makes it possible to mine ore bodies that otherwise could not be mined, but it also reduces labor cost where it is used. The drudgery of manual labor, especially in track laying, track shifting, and track maintenance, is eliminated by belt systems. 39

In 1941, there were only 6 belt conveyor installations, having an aggregate length of 9,110 feet in operation on the iron range. In 1949, there were 26 conveyors, having an aggregate length of 32,465 feet, transporting ore in open pits on the iron range.

The most popular combination for open pit ore work is the 30 inch wide conveyor, operating at speeds of from 500 to 550 feet per minute. Where wet or chunky ore is contemplated prior to installation, 36 inch belts are used.

For the shorter belts with a low lift, ordinary duck type belts are used, but in the installation where long flights with high lifts are contemplated, cotton or rayon cord as a special flexible-fabric belts are used to provide safety

factors for high belt tensions. In cases of extreme length and lifts, steel cord belts have been installed.

Spacing of troughing idlers is under going change on the long haul belt. The troughing idlers are spaced at 2-1/2 foot centers at the end, where belt tension is low, to avoid sag between idlers. At the upper end of the conveyors a spacing of 4 foot centers is maintained where belt tension is high and less tendency to sag is encountered.

Antifriction bearings are generally used in the idlers and pulleys. Drives are usually directly connected from motor to reducers to head shafts. These drives are ordinarily of the single type but in long haul, high lift installations, dual or tandem drives are used. Due to the possibility of accident or power failure, backstop protection is provided, usually of the magnetic thruster type, either on the head shaft or on the reducer high speed shaft. 40

Skip Haulage

The most recent departure from conveyor belt transportation in open pit practices, utilizes skip hoisting up the side slope of the pit. Deep and narrow orebodies, subject to rapid increase in depth that discourage use of conveyor belts and necessary crushing plants, are ideal for this system. 40)

Figure 23  Large Dragline Using Conveyor Haulage

Figure 24  Open Pit Using Skip Hoisting
The skip haulage method was developed to combine the desireable features of conveyor, truck, and rail haulage and at the same time avoid the draw backs. The skip is designed to follow the natural angle of repose of the pit wall and can vary from 25 to 40 degrees. Open pit skips now in operation show that the installation is successful and provides the operator with a short, level haul for trucks, low maintenance, and investment with high flexibility.

The skip method can be co-ordinated with present mining methods. Ore loaded is trucked to the skip. Fewer trucks are used and no new equipment is needed. Standby equipment is reduced and only one spare skip is necessary. It is the goal of the operators to eliminate the crushing in the pit. Skips are able to handle any material that trucks can haul and therefore crushing and sizing can wait until the ore reaches the surface. The plant can be permanently located and only provisions for moving the truck dump are necessary as the pit floor retreats.

"The skip installations in operation were subjected to comparison by one company operating with trucks and conveyors in addition to the skip system. A cost analysis indicated that the skip gave the lowest operating cost per ton. It was also determined that like a conveyor, the skip gave short truck hauls on pit bottom, requiring less improved roadway for pit access, and minimum personnel. The inclined skip
permitted flexibility in following the pit bottom down, and
a crushing plant was not necessary in the pit."41

In some open pit mines, drainage is a major problem while at others it is not considered a problem at all. In most of the iron mines drainage is a problem while at the open pit copper mines it is not so important.

On the Mesabi Iron Range the water table is only about 40 feet from the surface and the pits are sumps so drainage is required. Most of the mines are drained by means of a drift under the long dimension of the pit. The bottom of the pit is drained by the drift through drill holes, and the drift connects with a shaft where pumps are installed. A few mines are drained by wells drilled at the edge of the pits, and in some the water is collected and pumped from sumps in the pit. Deep well, sump pumps, or centrifugal pumps are used at nearly all pits.

In the copper mines there originally was no pumping problem as mines on mountain sides do not become sumps. All of the open pit copper mines have been extended below the ground surface and pumping is practiced. At most copper mines the water is either drained by underground workings or pumped out of the mines by using wooden pipe, rubber lined pipes or concrete flumes. This is necessary because of the corrosion effect of the water.

At the Utah Copper pit at Bingham, Utah, the water is
pumped vertically to the main haulage adit, where it is drained from the pit by gravity. This is a cheap method of drainage where topographic advantages occur.

One of the toughest jobs of dewatering was done at the Morton Pit of the M. A. Hanna Company, near Hibbing, Minnesota. A pumping rate of 4,500,000 gallons per day must be maintained to stabilize the water level in the pit and much higher rates are required to lower this level. When the first stripping cut was started, water in quantity was found within 5 feet of the surface. Three 1,500 gallon per minute deep well pumps were installed in the old concrete shaft and a drainage ditch, 60 feet deep, 200 feet wide, 1,500 feet long, and deepened at one end to form a sump, was cut along the south side of the stripping area. As water collected, additional sumps were dug and pumps installed; at peak periods as many as six were in service. It should be pointed out that this continuous pumping, allowed stripping to double for the first year of operation. 42

POWER SUPPLY TO OPERATING EQUIPMENT

Because of the mobility of operations in open pits, power distribution must be such that it can be moved as need arises. Electrically operated equipment is serviced by trailing cable, but metal towers are available to get lines and brackets for the support of trolley lines; these poles are on skids so they can be moved easily. Cable outlets, power lines, and transformers are arranged to conform to bench operations with a minimum of power loss.

Where air operated drills are used, air supply is of major importance. In pits where there is a central compressor plant, air lines are laid on the ground. Using this system air loss and maintenance of line is a constant headache to operators and runs up the cost considerably. One open pit mine went to self contained compressor and drill units because of the cost of air loss alone.

When you consider the time, labor and money involved in supplying power to equipment you can see the advantage of self contained drill units, diesel rail haulage, truck haulage, and diesel operated shovels. The cost of power varies as locality and amount of power available. A change in the cost of power in a certain locality can change the mining cost in a pit considerably.
Open pit mining is the oldest type of mining method, although it was not until 1877 that heavier equipment was first used in an open pit. Since then, larger and better equipment has decreased open pit cost, while the cost of underground mining has increased.

Open pit mining is especially adapted to flat lying deposits where the amount of overburden to be removed does not prohibit this method. Surface outcrops are also sometimes mined by this method.

There are many methods of planning a pit but before any mining can be done, the size of the orebody and the grade and tonnage of the orebody must be calculated from the exploration drill holes. After this, mining plans can be completed. With better drilling and loading equipment, the height of benches can be kept larger today than years ago.

The churn drill and percussion drill was used extensively for blast hole drilling until rotary drills came into use in the mining industry. Today more and more mines are going to this type of drill.

There are many types of blasting, but all are classified under either vertical or horizontal holes. Some mines drill many holes and blast them all at once and some mines blast the holes they drill every day. Blasting large holes has cut down secondary blasting and blasting cost considerably. Large holes are also superseding springing which is dangerous
because of danger of premature explosions. Blasting in iron mines just loosens the material for the shovel, while heavy charges are needed in hard ore mines.

Once the blast is detonated, open pit mining becomes just another form of earthmoving. The main problem here is the proper scheduling of digging and maintaining the right balance between haulage and loading units so they are not idle.

Shovels in use in open pits range from 3/8 cubic yard to 60 cubic yard capacity, and are either electric, diesel or gasoline driven. The new trend is toward the development of large capacity shovels so that higher benches may be maintained. Draglines are used in deep cuts and soft material are used well in connection with conveyor haulage. Draglines with 30 cubic yard buckets and ability to dig down 100 feet are not common.

In many foreign countries, bucket wheel excavators are used in easy digging sand, gravel, shale, clay, which overly the ore zone. Digging heights go as high as 230 feet and some machines dig very impressive depths. Front end loaders and power drawn scrapers are also used in open pits but not as much as other loaders. Scrapers are used in stripping soft overburden on large jobs and front end loaders are used mostly for cleanup.

Operators now have a much better choice in the selection of haulage equipment. Truck and conveyor systems and truck
and skip systems have made it possible to mine orebodies that otherwise could not be touched.

In most pits using rail haulage, the old steam locomotive has been replaced by either diesel, electric or a combination of the two. Most of the cars in use are from 50 to 75 tons and are either hopper bottom or side dump cars. Tracks at all the United States open pit mines are standard guage and the tendency is toward heavier track as heavier equipment comes into use.

In the last 20 years tremendous improvements have been made in the design of large trucks and now combinations of trucks, conveyors, and skip can compete with rail haulage. Trucks can negotiate curves and grades which are not passable by trains although decent roads must be maintained for trucks. Trucks used in open pits have rated capacities of up to 70 tons and usually carry more than rated capacity.

Other advances in the haulage system is the use of conveyors and skips in pits with high grades. Conveyors have the advantage of replacing much manual labor and are preferred in mines where they are now being used. In deep and narrow orebodies subject to rapid increase in depth, skips hoisting up the side slope is utilized. This method can be co-ordinated with other methods of transportation as depth is reached in a pit.

In some mines drainage is a major problem and some mines
are not concerned with it. The most common methods of draining open pits is to either pump water up out of a sump where it is collected, or to drive a drift under the pit and drain into this through drill holes. In mines using haulage adits, the water is pumped to the adit and allowed to drain from there.

Power in open pits must be mobile so it can be moved as need arises. Power supply should be close to the equipment using it, to hold down the power loss in transmission.
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<table>
<thead>
<tr>
<th>NAME OF MINE</th>
<th>LOCATION</th>
<th>TYPE OF ORE</th>
<th>ORE OCCURRENCE</th>
<th>WASTE ORE RATIO</th>
<th>BENCH HEIGHT</th>
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</thead>
<tbody>
<tr>
<td>Berkeley Pit</td>
<td>Butte, Montana</td>
<td>Chalcocite</td>
<td>Secondary Enriched Zone</td>
<td>1.9 to 1</td>
<td>25 Ft (Ore)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50 Ft (Waste)</td>
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<tr>
<td>Chuquicamata</td>
<td>Chile</td>
<td>Cu Sulphate Chalcocite</td>
<td>Porphyry Copper</td>
<td>.75 to 1</td>
<td>52.5 Ft</td>
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<tr>
<td>Eagle Mt. Mine</td>
<td>So. California</td>
<td>Hematite Magnetite</td>
<td>Bedded</td>
<td>1 to 1</td>
<td>30 Ft</td>
</tr>
<tr>
<td>Gunnar Mine</td>
<td>No. Saskatchewan</td>
<td>Uranium Oxides</td>
<td>Bedded</td>
<td>2.5 to 1</td>
<td>30 Ft</td>
</tr>
<tr>
<td>King Island Mine</td>
<td>Australia</td>
<td>Scheelite</td>
<td>Bedded</td>
<td>1 to 1</td>
<td>20 Ft</td>
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<tr>
<td>Lavender Pit</td>
<td>Bisbee, Arizona</td>
<td>Chalcocite</td>
<td>Porphyry Copper</td>
<td>1 to 1</td>
<td>50 Ft</td>
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<tr>
<td>Mac Intyre Pit</td>
<td>Tahawas, N.Y.</td>
<td>Ilmenite Magnetite</td>
<td>Vein Outcrop</td>
<td>1.4 to 1</td>
<td>35 Ft</td>
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<tr>
<td>Marmora Mine</td>
<td>Ontario</td>
<td>Magnetite</td>
<td>Bedded</td>
<td>----</td>
<td>45 Ft</td>
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<tr>
<td>Musonoi Mine</td>
<td>Katanga, Belgium Congo</td>
<td>Chalcocite Carrollite</td>
<td>Secondary Enriched Zone</td>
<td>1.5 to 1</td>
<td>10 Meters</td>
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<tr>
<td>Oxide Pit</td>
<td>Silver Bell, Arizona</td>
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<td>Porphyry Copper</td>
<td>1 to 1</td>
<td>40 Ft</td>
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<tr>
<td>Replier Mine</td>
<td>Minersville, Penn.</td>
<td>Coal</td>
<td>Bedded</td>
<td>7.5 to 1</td>
<td>120 Ft</td>
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<tr>
<td>Reserve Pit</td>
<td>Babbit, Minnesota</td>
<td>Taconite</td>
<td>Bedded</td>
<td>----</td>
<td>35 Ft</td>
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<tr>
<td>Ruth Pit</td>
<td>Ruth, Nevada</td>
<td>Chalcocite</td>
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<td>1.5 to 1</td>
<td>50 Ft</td>
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<tr>
<td>Utah Copper Mine</td>
<td>Bingham Canyon, Utah</td>
<td>Chalcocite Chalcopyrite</td>
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<td>50 Ft</td>
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<tr>
<td>Yerington Pit</td>
<td>Weed Heights, Nevada</td>
<td>Chalcocite Chrysocolla</td>
<td>Porphyry Copper</td>
<td>1.7 to 1</td>
<td>25 Ft</td>
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## Ding Operations

<table>
<thead>
<tr>
<th>Size of Pit</th>
<th>Ore Prod. Per Day</th>
<th>Drilling Equipment</th>
<th>Loading Equipment</th>
<th>Transport Equipment</th>
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<tr>
<td>Length</td>
<td>Width</td>
<td>Depth</td>
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<td></td>
</tr>
<tr>
<td>4600 Ft</td>
<td>2600 Ft</td>
<td>1086 Ft</td>
<td>17,500 Ton</td>
<td>Rotary</td>
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<tr>
<td>8850 Ft</td>
<td>3540 Ft</td>
<td>980 Ft</td>
<td>105,000 Ton</td>
<td>Churn</td>
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<tr>
<td>----</td>
<td>----</td>
<td>650 Ft</td>
<td>14,000 Ton</td>
<td>Churn</td>
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<tr>
<td>975 Ft</td>
<td>775 Ft</td>
<td>300 Ft</td>
<td>1,250 Ton</td>
<td>Percussion</td>
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<tr>
<td>1400 Ft</td>
<td>222 Ft</td>
<td>140 Ft</td>
<td>1000 Ton</td>
<td>Percussion</td>
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<tr>
<td>3100 Ft</td>
<td>2400 Ft</td>
<td>1000 Ft</td>
<td>37,500 Ton</td>
<td>Rotary</td>
</tr>
<tr>
<td>2400 Ft</td>
<td>800 Ft</td>
<td>500 Ft</td>
<td>5200 Ton</td>
<td>Percussion</td>
</tr>
<tr>
<td>2600 Ft</td>
<td>1800 Ft</td>
<td>----</td>
<td>30,000 Ton</td>
<td>Rotary</td>
</tr>
<tr>
<td>2200 M</td>
<td>150 M</td>
<td>100 M</td>
<td>5,000 Ton</td>
<td>Churn</td>
</tr>
<tr>
<td>2100 Ft</td>
<td>1500 Ft</td>
<td>300 Ft</td>
<td>----</td>
<td>Churn</td>
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<tr>
<td>----</td>
<td>----</td>
<td>----</td>
<td>2,200 Ton</td>
<td>Rotary</td>
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<tr>
<td>9 Miles</td>
<td>2700 Ft</td>
<td>175 Ft</td>
<td>50,000 Ton</td>
<td>Flame Piercing</td>
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<td>5400 Ft</td>
<td>3000 Ft</td>
<td>700 Ft</td>
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<tr>
<td>6000 Ft</td>
<td>4000 Ft</td>
<td>2000 Ft</td>
<td>100,000 Ton</td>
<td>Percussion</td>
</tr>
<tr>
<td>4500 Ft</td>
<td>1800 Ft</td>
<td>450 Ft</td>
<td>10,000 Ton</td>
<td>Rotary</td>
</tr>
</tbody>
</table>